HELSINKI SCHOOL OF ECONOMICS
Department of Economics

# OPTIMALITY OF INTERNATIONAL ENVIRONMENTAL AGREEMENTS: QUOTA MANAGEMENT AND TECHNOLOGICAL COOPERATION IN CLIMATE CHANGE MITIGATION



Master's Thesis in Economics
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**ABSTRACT**
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OPTIMALITY OF INTERNATIONAL ENVIRONMENTAL AGREEMENTS: QUOTA MANAGEMENT AND TECHNOLOGICAL COOPERATION IN CLIMATE CHANGE MITIGATION

International environmental agreements are negotiated to reduce the impact of negative externalities from production and consumption to the global environment. Efficient cooperation demands by definition that such agreements are Pareto-optimal.

There are many ways to analyze international multilateral agreements and an intriguing theoretical approach lies in modern economics. By game theory we can analyze the different incentives for the negotiating parties to join the coalition and formulate a theoretical framework on how to create efficient environmental agreements.

I study the optimality of treaties based on emission quotas and compare these quota agreements to treaties based on technological cooperation in theory. I use the Kyoto Protocol as an example of a quota agreement and the Asia Pacific Partnership on Clean Development and Climate initiative as an example of an agreement based on technological cooperation. I compare the potential of these two approaches to reduce greenhouse gas emissions for effective climate change mitigation.

The study shows that agreements based on abatement quotas may fail because they are not able to create strong enough incentives for all the negotiating parties to join the coalition and comply with their emission quotas. The greenhouse gas emission reductions produced by the current coalition of the Kyoto Protocol appear to be far too small to have an observable impact on climate change. On the other hand, agreements based on technological cooperation seem to fail to induce efficient cooperation in the absence of collective technological funding and control on the diffusion of the technologies, as is the case with the Asia Pacific Partnership on Clean Development and Climate. I conclude that an agreement that efficiently combines quota management and technological cooperation would Pareto-dominate any contract based on only one of these mechanisms.

**Keywords:** APPCDC (Asia Pacific Partnership on Clean Development and Climate), climate change, game theory, international environmental agreements, Kyoto Protocol, Pareto-optimality, quota management, technological cooperation, UNFCCC (United Nations Framework Convention on Climate Change)

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KANSAINVÄLISTEN YMPÄRISTÖSOPIMUSTEN OPTIMAALISUUS: KIINTIÖSOPIMUKSET JA TEKNOLOGINEN YHTEISTYÖ ILMASTONMUUTOKSEN LIEVENTÄMISESSÄ

Kansainvälisiä ympäristösopimuksia pyritään solmimaan tuotannon ja kulutuksen ympäristölle aiheuttamien haitallisten ulkoisvaikutusten vähentämiseksi. Tehokas yhteistyö voidaan määritelmän mukaan saavuttaa ainoastaan Pareto-optimaalisilla sopimuksilla.

Kansainvälisiä multilateraalisia sopimuksia on tutkittu kirjallisuudessa monilla tavoilla, joista eräs kiinnostava teoreettinen lähestymistapa on modernin kansantaloustieteen peliteoria. Peliteorian avulla voidaan tutkia neuvotteluosapuolten kannustimia liittyä sopimukseen ja luoda teoreettinen viitekehys tehokkaiden kansainvälisten ympäristösopimusten solmimiseksi.

Tutkin päästökiintiöihin perustuvien ympäristösopimusten optimaalisuutta ja vertaan näitä teknologiseen yhteistyöhön perustuviin sopimuksiin teoreettisesta näkökulmasta. Käytän esimerkkeinä tutkimuksessani päästökiintiöihin perustuvaa Kioton Protokollaa ja teknologiayhteistyöhön pohjautuvaa Asia Pacific Partnership on Clean Development and Climate aloitetta. Vertailen näiden lähestymistapojen mahdollisuuksia vähentää kasvihuonepäästöjä ja puuttua ilmastonmuutokseen.

Tutkimuksestani käy ilmi, että pelkästään päästökiintiöihin perustuvilla sopimuksilla on vaikeaa luoda kaikille maille riittävät kannustimet liittyä sopimukseen ja pitää kiinni päästökiintiöistään. Myös Kioton Protokollan tuottamat kasvihuonepäästövähennykset näyttävät olevan liian pieniä vaikuttaakseen ilmastonmuutokseen ajoissa ja riittävässä määrin. Toisaalta näyttää siltä, että teknologiayhteistyöhön perustuvat sopimukset eivät pysty luomaan tehokasta yhteistyötä ilman kollektiivisia teknologiatukia ja sääntöjä teknologian levittämisestä. Tämä on myös Asia Pacific Partnership on Clean Development and Climate aloitteen suurin puute. Tutkimukseni perusteella voidaan todeta, että päästökiintiöt ja teknologiayhteistyön tehokkaasti yhdistävä sopimus yltäisi parempiin lopputuloksiin kuin kumpikaan näistä yksin.

**Avainsanat:** APPCDC (Asia Pacific Partnership on Clean Development and Climate), ilmastonmuutos, kansainväliset ympäristösopimukset, kiintiösopimukset, Kioton Protokolla, Pareto-optimaalisuus, peliteoria, teknologinen yhteistyö, UNFCCC (United Nations Framework Convention on Climate Change)

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# 1 Introduction

International environmental agreements (IEAs) are typically negotiated in order to reduce the effects of negative externalities in consumption and production. Results from alarming studies on climate change (IPCC 2001, UNEP 2002, Watkiss *et al.* 2005) have recently made apparent an urgent need for an IEA to target greenhouse gas emissions in order to slow down global warming. The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1997 with high aims to slow down global warming by imposing emission reduction quotas to participants to the agreement. At present, the Protocol has entered into force with 164 members, but some recent studies (Babiker *et al.* 2002, Carraro and Buchner 2004) show that the refusal of the United States to ratify the Kyoto Protocol has a strong negative impact on the environmental effectiveness of the Protocol.

As a complement to the Kyoto Protocol, the United States and Australia have initiated a new non-treaty partnership for climate change management based on technological cooperation. India, Japan, the People's Republic of China and South Korea have also joined the Asia Pacific Partnership on Clean Development and Climate (APPCDC) even after previously ratifying the Kyoto Protocol. This initiative has met much critique for the lack of collective research and development (R&D) funding and control for technological diffusion.

The current challenge for climate change management is how to create effective and mutually beneficial cooperation to slow down climate change and how to induce all countries to cooperate in an efficient and effective way to reach the socially optimal level of greenhouse gas (GHG) abatement.

## 1.1 International environmental agreements

Global warming among several other international environmental issues has created a need for international cooperation to reduce the negative effects of externalities related to climate change. Externalities represent incidental costs or benefits to parties they are not specifically intended for. Externalities enter the utility or production function of another party without permission or compensation, and in the case of emissions they lead to free riding incentives for the emitters. (Hussen 2004.) Externalities can be local, regional or global and greenhouse gases are a current example of an essentially global externality. This is why it is argued that an international environmental agreement targeting greenhouse gases should restructure the incentives of all countries to induce global cooperation and efficiently reduce the emissions. Otherwise the abatement efforts of some countries may lead to increased emissions of others free riding on the agreement (Carraro and Moriconi 1997).

There are already around 225 multilateral environmental agreements in the world (Barrett 2003), but only some of these have been successful in cover and even fewer in results. The main problem with implementation of IEAs is the free riding incentives to the non-participating countries created by the actions of signatories. The positive effect from the actions of the coalition is often offset by the actions of the non-participating countries. (Carraro and Siniscalco 1993.)

Many of the numerous environmental agreements have had difficulties in binding all the negotiators to the actual agreement, or have only bound them with vague and general targets that are easily reached (Barrett 1999). The literature seems to show that only limited benefits may be reached with a globally binding agreement and only small coalitions tend to arise from global negotiations of IEAs with considerable benefits. This raises the question; how could all the negotiating countries be motivated to ratify environmental agreements in order to reach tangible results?

## 1.2 Kyoto Protocol to the United Nations Framework Convention on Climate Change

The Kyoto Protocol is an amendment to the United Nations Framework Convention on Climate Change that came into force in February 2005 and already legally binds 164 states covering over 61% of the world's greenhouse gas emissions (UNFCCC

2006). However, two of some of the most significant emitters, the United States and Australia, have not ratified the Kyoto Protocol even though they are members of the UNFCCC. As a result, the Kyoto Protocol seems bound to fail in its initial target to reduce the greenhouse emissions on average 5.2% below the 1990 baseline over the 2008 to 2012 period and the impact on global warming may be lower than anticipated.

The obligations of the Protocol only bind those parties to the UNFCCC that have also ratified the Kyoto Protocol and it only imposes targets for greenhouse gas abatement for developed countries and some European Economies in Transition (EITs).[1] Developing countries were excluded from the requirements of the Kyoto Protocol as they were not the main contributors to the greenhouse gas emissions during the industrialization period. (UNFCCC 2006.)

The initial target of the UN Framework Convention was to reduce emissions of greenhouse gases in developed countries below the 1990 level by the end of the 20th century, a goal which was successfully achieved when these emissions fell by 6,6%, far below the 1990 level by the end of 2000. However, the first target of the Kyoto Protocol, to reduce emissions of six greenhouse gases below the 1990 level by 5,2% during the first control period of 2008-2012, seems much more difficult to achieve as some significant emitters have not ratified the Kyoto Protocol.

## 1.3 Asia Pacific Partnership on Clean Development and Climate

The Asia Pacific Partnership on Clean Development and Climate is an international non-treaty agreement between Australia, India, Japan, the People's Republic of China, South Korea, and the United States. The cooperation was announced in July 2005 at the Association of South East Asian Nations (ASEAN) Regional Forum meeting and the agreement was launched on January 12th 2006 at the Partnership's Ministerial meeting in Sydney. The participating countries agreed to cooperate on development and transfer of technology that enables reductions of greenhouse gas emissions. (APPCDC 2006a.)

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[1] See Appendix 1 for individual abatement targets.

The member countries account for about 50% of the world's greenhouse gas emissions, and unlike the Kyoto Protocol with mandatory limits to greenhouse gas emissions, the non-legally binding APPCDC allows member countries to individually set their targets for reducing their emissions, with no mandatory abatement targets and no enforcement mechanism. This has raised much criticism, as the agreement is considered inefficient with no enforcement.

The Partnership is consistent with the efforts of the United Nations Framework Convention on Climate Change and the aim of the agreement is to complement, rather than replace, the Kyoto Protocol (APPCDC 2006b). This is why some of the members of the Kyoto Protocol have also agreed on APPCDC.

## 1.4 Previous research

There is an abundance of interesting studies about international environmental agreements from a game theoretic point of view. I concentrate especially on ones that study abatement quotas and technological cooperation in climate change management, but also discuss numerous studies that concentrate on expanding stable coalitions.
Finus and Rundshagen (1998) find that with pure quota management, cooperation is restricted by the rule of the lowest common denominator and cooperation can never reach the social optimum with pure quota management. Barrett (1999) concludes further that full cooperation may only be sustained when the number of cooperating parties is small or when the gains from cooperation are small in relation to the non-cooperative equilibrium.

According to Barrett (2002), an agreement based on technological cooperation would provide positive incentives for participation and a more efficient second best alternative than a quota management agreement. Buchner *et al.* (2002) find that whenever there are relevant excludable benefits from technological cooperation, all countries cooperate in a stable and profitable coalition. Similarly Golombek and Hoel (2005) conclude that it is beneficial to include technological issues in an agreement whenever there are positive international spillovers from technological progress. However, Buchner *et al.* (2002) also find that global aggregate emissions would rise as a consequence of the intensified R&D efforts if a technological agreement were adopted instead of the current coalition of the Kyoto Protocol.

Many studies (Barrett 2003, Hoel and Schneider 1997 and Heal 1994) estimate the size of stable coalitions and a general conclusion seems to be that only a small coalition tends to cooperate in the equilibrium while full cooperation is only sustained with minimal gains from cooperation. This general result appears to hold in the reduced form stage framework as well as in a dynamic setting.

Several studies have found transfers to be able to increase the size of the stable coalition (Carraro and Siniscalco 1993, Kaitala and Pohjola 1995, Petrakis and Xepapadeas 1996). On the other hand, Hoel and Schneider (1997) find that the effect of transfers may also be negative. The linkage of environmental negotiations to other economic issues also seems to increase the size of the stable coalition (Carraro and Siniscalco 1998). Breton and Soubeyran (1997) find a strong correlation between trade policy and environmental policies and Carraro and Siniscalco (1998) show that the linkage of environmental protection with other economic issues may increase the number of cooperating countries. Specifically, Katsoulacos (1997) concludes that joint support for research joint venture subsidies combined with the environmental agreement may result in a first-best optimal level of emissions.

Barrett (1997) finds that a credible threat to impose trade sanctions may sustain full cooperation in environmental cooperation when accompanied by a minimum participation clause, but Carraro and Siniscalco (1998) note that signatories may in fact lose from carrying out sanctions thus making any threats implausible. Some studies (Bloch 1997, Carraro and Siniscalco 1998, Asheim *et al.* 2003) also find that two or more coalitions define the optimal equilibrium of the game. Finus and Rundshagen (2003) conclude that any equilibrium coalition structure other than the single coalition structure Pareto-dominates the case of one global agreement.

I discuss literature on abatement quotas in section 4 and technological cooperation in section 5 turning to the issue of expanding the coalitions in section 6.

## 1.5 Research question

The objective of this study is to use game theory to examine the formation of coalitions in international environmental agreements with quota management and technological cooperation and study solutions to expand their coverage and benefits to member states. I seek an answer to the question: What is the optimal way to form environmental agreements? From a game theoretic aspect, the research question is: How can the Pareto-optimal equilibrium be reached with an environmental agreement?

I expect the study to demonstrate that quota management and technological cooperation in climate change combat offer different incentives. The hypothesis is that agreements based only on abatement quotas or technological cooperation fail to reach efficient outcomes, while different solutions for making Pareto-optimal changes to the agreement are available.

## 1.6 Research method

In this study, I review the economic literature on international environmental agreements. I limit the research to game theoretic literature and employ a game theoretic approach to study quota management and technological cooperation in climate change management. I examine the Kyoto Protocol to the United Nations Framework Convention on Climate Change and the Asia Pacific Partnership on Clean Development and Climate as examples of quota management IEAs and those based on technological cooperation respectively. I explain the mechanisms behind these agreements and study the choices of members in the negotiations by game theory. Finally I consider different ways to make Pareto-improvements to such agreements.

## 1.7 Theoretical approach

Game theory provides an interesting approach to the choices of the negotiating countries and a game theoretic approach can be applied to study the incentives offered by the agreements. Game theory is the study of multiperson decision problems and analyzes the choices of economic agents under uncertainty of choices of other agents. In games, strategic choices are based on expectations on other agents' choices and games often lead to equilibria that are not Pareto-optimal. A classic example of this is the *Prisoners' Dilemma*. (Gibbons 1992.)

Pareto-optimality defines an allocation of resources where no movement can be made from one allocation to another making at least one individual better off without making any other individual worse off (Fudenberg and Tirole 1991). The underlying game in international environmental agreements with abatement quotas is usually assumed to be a *Prisoners' Dilemma* and lead to the free rider's problem and the *Tragedy of the Commons*. In the *Prisoners' Dilemma*, cooperating is strictly dominated by defecting, so that the equilibrium for the game is for all players to defect even though each player's individual benefit would be larger if they all played cooperate (Dresher 1961).

Free riders gain from the efforts of the member states at no cost and they may even increase their own load to the environment while the parties of the agreement struggle to decrease their impact. The damages from the equilibrium represent the *Tragedy of the Commons*, with a conflict between individual interests and the common good. In terms of pollution, each individually rational player finds that his share of the damage from pollution is less than the cost of abatement (Hardin 1968). With different assumptions on the qualities of negotiating parties or by expanding the handling to the model of the dynamic game, several other equilibria can be found. Still, the problem of international environmental externalities is fundamentally a problem with no first best solution. The principle of sovereignty only allows second best solutions (Barrett 2002).

In a climate change regime based on technological cooperation, the incentives are different and excludable technological benefits induce countries to cooperate in a global coalition. Coalition formation with technological cooperation is studied as reduced form stage games and dynamic games, where international technological spillovers are introduced to the individual profit functions. It appears that all countries cooperate in a stable and profitable coalition whenever there are relevant excludable benefits from cooperation. However, other problems arise as technological advances also increase production and may even increase total emissions as a result. (Buchner *et al.* 2002.)

This game theoretic approach may be used to study the establishment of efficient international environmental agreements. I limit my discussion to the economic game theoretic approach and study the different qualities of agreements based on quota management and technological cooperation in the light of this theory introduced in section 3.

## 2 Background

Climate change is a current and severe environmental problem and it seems obvious that efficient international cooperation is needed to tackle the challenges presented by several alarming studies (IPCC 2001, UNEP 2002, Watkiss *et al.* 2005) on climate change. According to the IPCC Climate Change Synthesis report (2001), "Human activities have increased the atmospheric concentrations of greenhouse gases and aerosols since the pre-industrial era. The atmospheric concentrations of key anthropogenic greenhouse gases (...) reached their highest recorded levels in the 1990s, primarily due to the combustion of fossil fuels, agriculture, and land-use changes." The report provides strong evidence that most of the warming observed over the last 50 years is attributable to human activities. These observations highlight the urgency of the issue and provide justification for the need of international cooperation to combat global warming.

In this section I demonstrate the dilemma of transnational cooperation caused by negative externalities, introduce the general process of treaty-making and present basic background information on the UNFCCC and Kyoto Protocol as well as the Asia Pacific Partnership on Clean Development and Climate.

### 2.1 Transnational cooperation dilemmas

Transnational and international environmental cooperation and specifically environmental agreements are usually initiated to target environmental externalities. An externality arises when an agent's actions have an impact also on other agents and a transnational externality describes a situation where one country's actions affect some other countries (Kolstad 2000). An example of a local transnational environmental externality is acid rain created by sulfur and nitrogen oxides. The emissions create acid rain in the source country of the pollution as well as in the neighboring countries. Specifically, an international environmental externality arises when a country's actions have a global impact on all other countries' environment as in the case of greenhouse gas emissions or $CO_2$ -emissions. (Barrett 2003.)

Externalities lead to wrong incentives since they represent a cost or benefit not included in the producer's production costs. In this case, production has an impact on other agents' utilities that bears no impact on the costs or benefits of the producer. Externalities usually have an impact on both production relationships and utility relationships. Excessive fishing, for example, may harm some fisheries while search costs rise and yields decline. Similarly, depletion of the ozone layer, a negative externality from $CO_2$ -emissions, may damage crops and fisheries. Specifically, an increase in greenhouse gas concentrations may raise global mean temperature and sea level and affect many sorts of climate-sensitive sectors such as agriculture. These are examples of changed production relationships, but simultaneously externalities may affect utility relationships also. Examples of changed utility relationships are loss of clean environment for all people affected by pollution and an increase in the frequency of skin cancer because of the depletion of the ozone layer (Barrett 2003.)

Greenhouse gas emissions will expectedly have both an impact on production relationships between nations and an impact on individual utility levels. By changing the global climate, greenhouse gases will influence the production relationships of fishery, agriculture and many other sectors while the climate change and sea level rise will have a direct impact on the utilities of individuals by making some areas uninhabitable and others more favorable.

The goal of most international environmental agreements is to internalize these externalities in order to reduce their negative effects. For example, by imposing limits to emissions, an environmental agreement forces the signatories to reduce national emissions by either developing clean technologies or by reducing polluting production. Similarly, an environmental agreement on technological cooperation induces efforts to develop and diffuse clean technologies for production and consumption. The extra costs imposed to producers as abatement limits by the national government work as internalized externalities as the producers are forced to consider the impact of their actions to the environment and decrease production and raise the prices or increase their efforts to develop clean technologies. Thus the externalities are added to other costs of production and are gradually internalized to the producer.

As in the case of the Kyoto Protocol, an international environmental agreement may impose abatement targets to the signatories and optimize the abatement costs by different kinds of project-based mechanisms that will be introduced in section 2.3.4. As another example, an IEA may merely induce development and transfer of technology to reduce the level of abatement and thus reduce the impact of externalities, as is the goal of the Asia Pacific Partnership on Clean Development and Climate.

## 2.2 The Process of treaty-making

Many attempts have been made to introduce international or transnational environmental agreements and at present, already some 225 multilateral environmental agreements have been more or less successfully established. By definition, IEAs are negotiated, written down in black and white and legally binding for all the countries that consent to be bound by them. (Barrett 2003.)

There are IEAs to address many different kinds of transnational environmental issues from conserving endangered species and unique ecosystems to preventing spread of pests and diseases or controlling fishing quotas. IEAs may set limits or standards, establish liability or set bans and regulations. At the same time, an IEA may only express intent of signatories and leave specific targets or regulations open. The variety of IEAs is almost as large as their number and the main feature in common for all the issues concerned is that they exhibit transnational externalities that need to be dealt with in order to optimally consume or preserve the target of the agreement.

The success as well as the problems are varied depending on the nature of the problem and essentially the costs of and benefits from solving the problem. I will follow Barrett (2003) to present the process of treaty-making in order to introduce some of the basic qualities of agreements and phases assumed in theory. As international environmental agreements are usually result of individual negotiation processes, not all of these qualities can be generalized to account for all the IEAs. However, these qualities are common in many of the modern IEAs and thus provide a good basis for the theoretic approach.

### 2.2.1 Negotiation

Negotiations of IEAs are normally preceded by a period of pre-negotiations where the interested parties state their views on their position and the targets for the negotiations in order to affect the outcome of the negotiations. These views may often be strategic in the sense that they attempt to exaggerate the costs of abatement or understate the benefits from cooperation. However, this preceding *cheap talk* seldom has an impact on the outcome since the other parties will not accept these claims as credible. The pre-negotiations often include intra-governmental negotiations where governments negotiate with several interest groups in order to maintain a position for the following negotiations. Some intergovernmental groups such as the EU may negotiate on their collective position in advance and also, some *ad hoc* intergovernmental groups are often formed before the negotiations in order to gain a bargaining advance over sovereign states or other coalitions.

Large negotiations usually start with an agreement on the process of decision-making. The process has a strong influence on the actual negotiations as the order of introducing alternatives or the preparation of the negotiating text is likely to have an impact on the results of the negotiations. After the process has been agreed on, the negotiations may proceed to the actual negotiation phase, where negotiation tactics play an important role.

The negotiators may choose whether to negotiate a single agreement or to break the negotiations up first negotiating a *convention* to establish basic principles and later negotiate *protocols* to specify the obligations and targets for the signatories. Usually states must first ratify the convention before signing any of the associated protocols and on the other hand, members of the convention are not obligated to sign the protocols. It is not evident that dividing the problem into separate issues will bring better overall results as linking the issues may sometimes lead to larger participation or higher abatement.

### 2.2.2 Ratification

Treaties usually enter into force by a formal process in which ratification is the most important issue. However, before the national governments choose to ratify an agreement, several other steps have been taken in the process. First a state signals its intent to comply with an agreement by having a representative sign the agreement. Signing an agreement obligates the country to refrain from undermining the objectives of an agreement and interfere with the choices of other countries to ratify, but it doesn't impose a legal obligation to ratify. In the example of the Kyoto Protocol, the former US president, Bill Clinton signed the treaty, but his successor George W. Bush decided not to seek ratification from the senate. In this case the signature binds the United States of America not to interfere with the ratification and implementation of Kyoto Protocol in other countries. Even though the ratification of an agreement is necessary for an agreement to be legally binding, it is often foreseen in the negotiation phase if the agreement will be ratified or not and thus the actual decision of ratification is often made earlier in the process.

### 2.2.3 Implementation

After ratification local governments must implement the treaty and typically this happens through the domestic legislation or by the adoption of implementing regulations. The local governments will however usually have free hands to choose the means of implementation and the different methods are numerous. Some typical means include quotas, tradable permits, taxes, product regulations and voluntary agreements. The implementation is essentially what defines the actual costs to producers or other institutions within the country. As the target is usually to internalize externalities of production, the goal is to define the costs according to the damage the different institutions impose on the environment.

Many IEAs require the parties to report data relating to their implementation and typically they are allowed to report their own implementation. This creates strong incentives to issue false or inaccurate reports in order to comply with the treaty even though the targets are not met. This is a challenge to modern IEAs and has created a need to monitor the implementation of the parties by a global authority or by the other signatories to the agreement. This however creates additional costs to the member states and also the monitoring activities are vulnerable to free riding. As a result, monitoring problems may even reshape the agreements since the negotiating parties may not want to impose targets that are difficult to monitor.

The treaties also often differ in the means of managing the target resource and many treaties leave the details of the targets to be decided later. The treaties often define meetings where the targets are regularly set for the next period. The rules and administration of the treaties also have an impact on the ratification of the treaties as too strict and immediately binding targets may be difficult for some parties to accept.

### 2.2.4 Renegotiation

Even though many agreements are legally binding, it is also evident that any agreement may voluntarily be renegotiated if all the parties are willing to change the terms. Obviously, the goal of negotiations is to design an agreement that will not be renegotiated since this will guarantee that the agreement is Pareto-optimal also in the future. However, in a world with uncertainty, unpredicted changes in the global environment may require renegotiation of the agreement. Under the definition of farsightedness, the negotiators would be able to foresee any future changes and negotiate the agreement so that these changes are incorporated in the implementation of the targets. This is why the possibility of renegotiation is sometimes included in the treaty in order to take precautions for any future changes.

A treaty may be amended, adjusted or simply replaced by a new agreement. Any negotiated adjustments bind all the original signatories to the agreement, but require the parties to ratify the amended agreement. They may become parties to the amended agreement, but they may also choose to remain in the original agreement and not ratify the amendment. This is why amendments to agreements should usually be regarded as separate agreements. The possibility of renegotiation is an important assumption in the theory. As any agreement may be renegotiated any number of times, the optimal agreement is designed so that it will never be renegotiated. This assumption of optimal agreement design is the dynamic equivalent to Pareto-optimality in the static framework and is often referred to as the renegotiation-proofness.

### 2.2.5 Entry into force

Many IEAs define limits of participation in order for the agreement to come into force. Some agreements only come into force after all the negotiating parties have ratified the agreement and other agreements set numerical targets for the number of ratifying countries or for other significant features of the participants. The need for a minimum participation clause seems obvious since most agreements only work for the benefit of the participants when sufficiently many other countries commit to the same obligations. If any country would unilaterally want to commit to an agreement, there would be no need for formal cooperation. Minimum participation serves to guarantee that the agreement will only bind the ratifying countries when it is in their collective benefit to form a coalition.

### 2.2.6 Treaty withdrawal

Even ratified members of agreements usually have the right to withdraw from a treaty and rights of withdrawal are often included in the agreement. Multilateral agreements usually allow a party to withdraw with a written notification and impose a time limit before the withdrawal takes effect. Withdrawal may be used as a threat or as a trigger for renegotiation and in the extreme case, withdrawal of a member may even terminate the whole treaty.

Withdrawal is however quite rare since countries often have little to gain by withdrawing. If they would have strong incentives to withdraw, they would probably have foreseen this already in the negotiation phase. Also, it may be argued that as a credible threat to withdraw will probably trigger renegotiation of the agreement, countries will not actually withdraw but rather participate in the renegotiation. This also imposes a restriction to agreement design. As the member states have the right to withdraw from or accede to an agreement at any time, the agreement must be self-enforcing in order to remain stable. This means that the incentives for the signatories must be structured so that they will not have an incentive to deviate from the agreement.

### 2.2.7 Basic obligations

The basic obligations to the ratifying parties vary much in design, but most treaties impose some sorts of obligations related to environmental issues. An agreement based on technological cooperation could similarly impose a specific type or level of co-operation for the parties. The aim of all obligations is to correct the wrong incentives created by the externalities and the reason for different target levels is that the marginal damage or the marginal cost of abatement to the parties varies. Uniformity in the obligations may not be cost-efficient because of the different marginal costs of abatement, but on the other hand non-uniform obligations may not be cost-efficient either when designed unoptimally. This is why it is argued that allowing the parties to relocate their entitlements by trade or other mechanisms rather than simply choosing the allocation levels in the negotiations better deals with cost-efficiency. The Kyoto Protocol addresses this problem with three project-based mechanisms that are introduced in section 2.3.4.

The basic obligations of the agreement have an important role in the ratification of the protocol. Sometimes too strict or arguably unfair obligations to some parties may prevent ratification of an agreement. This is the basic argument for the United States and Australia for not ratifying the Kyoto Protocol, as they would not accept the abatement targets imposed on them in the agreement. Even though it may be argued that the obligations are too heavy on some parties, the underlying motivation for not ratifying may rather be in the free riding incentives caused by moral hazard in environmental issues. The free riding incentives will be discussed in more detail in section 3.

## 2.3 United Nations Framework Convention on Climate Change and the Kyoto Protocol

The UNFCCC is an international treaty that binds 189 countries, reaching almost global coverage (UNFCCC 2006). It is a treaty designed to tackle the challenges of climate change, but it doesn't set any limits to emissions or rules for cooperation. It is a framework that introduces guidelines for the environmental cooperation and incorporates provisions with mandatory targets that are negotiated separately. The Kyoto Protocol to the United Nations Framework Convention on Climate Change is such a provision to UNFCCC and at present better known than the framework itself.

### 2.3.1 United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC) aims to reduce emissions of greenhouse gases in order to combat global warming. The UNFCCC was negotiated between 1990 and 1992 and opened for signature at the United Nations Conference on Environment and Development (UNCED), informally known as the Earth Summit, held in Rio de Janeiro in 1992. It entered into force in March 1994 after receiving the 55th ratification and today the treaty has 189 parties reaching nearly global cover (UNFCCC 2006). The UNFCCC is essentially a treaty that sets an overall framework for intergovernmental efforts to tackle the challenges created by climate change. Its stated objective is "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UNFCCC 1992).

As originally negotiated, the UNFCCC set no mandatory limits on greenhouse gas emissions for individual nations and contained no enforcement provisions. Instead, it included provisions for updates that would set mandatory emission limits to the ratifying parties of these protocols. The principal update is the Kyoto Protocol, which has since become much better known than the UNFCCC itself. The parties to the Kyoto Protocol agreed to a general target to recognize common but differentiated responsibilities, with a greater responsibility for reducing greenhouse gas emissions on the part of developed countries identified in Annex I of the UNFCCC (2006).

The UNFCCC classifies the parties to three annex groups with different responsibilities according to the parties' levels of economic development (*ibid.*):

**Annex I parties** – The industrialized countries that were members of the OECD (Organization for Economic Co-operation and Development) in 1992, plus countries with economies in transition (EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States. The Annex I parties agreed to reduce their emissions of greenhouse gases to target levels below their 1990 emissions levels by the year 2000.

**Annex II parties** – An annex I subset of 24 highly developed countries including the OECD members of Annex I. The Annex II countries are required to provide financial resources to the developing countries to help them undertake emissions reduction activities and to help them adapt to the adverse effects of climate change. In addition, they are required to promote the development and transfer of environmentally friendly technologies to EIT Parties and developing countries.

**Non-Annex I parties** – Mostly developing countries that are recognized by the Convention as being especially vulnerable to the adverse impacts of climate change, including countries with low-lying coastal areas and those liable to desertification and drought. Other non-Annex I parties include countries that are more vulnerable to the potential economic impacts of climate change response measures. The Convention emphasizes activities that answer the special needs and concerns of these countries, such as investment, insurance and technology transfer.

In addition, the 48 parties classified as least developed countries (LDCs) are given special consideration under the Convention on account of their limited capacity to respond to climate change and adapt to its adverse effects. Parties are urged to take full account of the special situation of LDCs when considering funding and technology-transfer activities.

Since the UNFCCC entered into force, the parties have met annually in Conferences of the Parties (COP) to assess progress in dealing with climate change. From the first COP in 1995 in Berlin, the parties have negotiated the Kyoto Protocol to establish legally binding obligations for developed countries to reduce their greenhouse gas emissions. The Kyoto Protocol is introduced in more detail below.

### 2.3.2 Kyoto Protocol

The Kyoto Protocol to the United Nations Framework Convention on Climate Change is an amendment to UNFCCC that was adopted in Kyoto, Japan in 1997 after two years of negotiations on the terms. The Protocol opened for signature in 1998 and entered into force in February 2005 after reaching the conditions of ratification by a minimum of 55 parties and coverage of at least 55% of $CO_2$ emissions by UNFCCC Annex I parties in levels of the year 1990. Today, the Kyoto Protocol legally binds 164 members[2] that account for over 61 percent of the emissions of $CO_2$ in Annex I countries (*ibid.*).

The Kyoto Protocol shares the Convention's basic objective, principles and institutions, but significantly strengthens the aims of the UNFCCC by committing Annex I parties to individual, legally-binding targets set in the Conferences of the parties to limit or reduce their emissions of carbon dioxide and five other greenhouse gases. The protocol binds only those parties to the UNFCCC that have also ratified the Kyoto Protocol. Most industrialized countries and some Central European Economies in Transition (EITs) have agreed to legally binding reductions in

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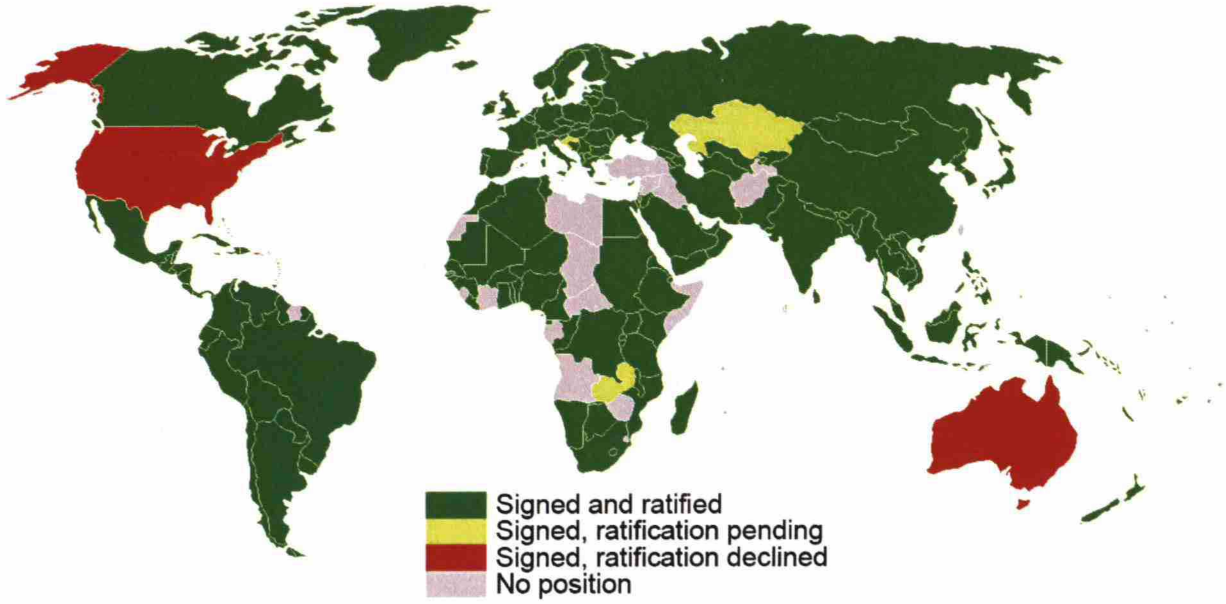
[2] See Picture 1 for participation to the Kyoto Protocol.




*Picture 1*. Participation to the Kyoto Protocol (Wikipedia 2006).

greenhouse gas emissions of an average of 6 to 8% below 1990 levels between the years 2008–2012 defined as the first emissions budget period (See Appendix 1 for detailed targets). These individual targets are listed in the Annex B of the Kyoto Protocol. Non-Annex I countries, essentially developing countries were excluded from the requirements of the Kyoto Protocol because they were not regarded as the main contributors to the greenhouse gas emissions during the industrialization period that is believed to be causing today's climate change. (UNFCCC 2004.)

Two notable members to the UNFCCC, Australia and the United States, have declined to ratify the Kyoto Protocol after signing it. United States justifies its cause by claiming that not imposing targets also to the developing countries would harm the economy of the United States (The White House 2006). This is a concern shared by Barrett (2003) who claims that the targets of the Kyoto Protocol may not be met without abatement targets to all the parties to the agreement. He concludes that the benefits from reductions in emissions in developed countries will be offset by increased emissions in developing countries.

The USA administration has also appealed on uncertainty of the science of climate change, but later recognized the impact of human activities together with the other G8 states and Brazil, China and India (The Royal Society 2006) after the strong evidence presented in a special report published by the Intergovernmental Panel on Climate Change (IPCC 2001). The report notes that most of the global warming observed over the last 50 years is attributable to human activities. Also Barrett (2002) argues that these reasons are invalid for not ratifying the Kyoto Protocol, as these problems may not be solved by any IEA.

Instead, he introduces some more valid arguments against the Kyoto Protocol, which may in his opinion be improved upon by a different agreement design. He criticizes the Kyoto Protocol for the low limit of emissions for entry into force. The 55% limit for Annex I countries only represents about 31% of global emissions and even currently the participants of the Kyoto Protocol that are required to reduce their emissions only account for about 34% of global emissions.

Another problem, created by the Kyoto Protocol mechanisms, is that they may be used for so called paper trades. This describes the situation when transactions are accepted for their cost reductions, and they do not provide corresponding benefits in emission reductions (Barrett 2003). Australia is concerned with the local unemployment strict abatement targets could cause and the Australian Prime Minister, John Howard, has argued that Australia is already doing enough to cut emissions. The Kyoto Protocol has raised much controversy in Australia as the opposition is in its strong support (Parliament of Australia 2006).

The largest problems with the Kyoto Protocol however are the clear flaws of the compliance mechanism and the lack of incentives for participation (Barrett 2002). The compliance mechanism requires the non-complying parties to punish themselves by reducing emissions by an additional 30% of their abatement target in the next period, while the targets for the targets for the next control period are still being negotiated. The compliance mechanism is described in more detail in section 2.3.3 below.

### 2.3.3 Agreement design

*Negotiation*

The negotiations on the Kyoto Protocol were conducted in two phases. First, specific targets for member states were agreed on in the third Conference of Parties (COP3) in 1997, while the project-based mechanisms and compliance mechanisms were negotiated later in the 2001 Marrakech Accords in order to implement the abatement cost-efficiently (UNFCCC 2004). Barrett (2002) criticizes this approach as in the first phase it was not clear if the treaty created incentives for broad participation. The negotiations should rather have begun with an agreement on a mechanism to achieve both broad participation and full compliance, and targets for reducing emissions should have been discussed for the long term. In the Kyoto Protocol, the targets for the next control period will be discussed in separate negotiations and the parties are not compelled to accept them. This obviously conflicts with the optimal design of agreements as the protocol is by definition renegotiated after the first control period.

*Ratification*

The Kyoto Protocol was opened for ratification in 1998. As mentioned in the section 2.2.2, signing the agreement doesn't impose a legal obligation for negotiating parties to ratify, and in the case of the Kyoto Protocol, Australia and the USA have declined to ratify the protocol after previously signing it (UNFCCC 2006).

*Implementation*

The Kyoto Protocol imposes specific targets to all the member states, but leaves the implementation of the abatement to the local governments of member states. Typically the implementation happens through domestic legislation or by the adoption of implementing regulations. The European Union has agreed to internally redistribute the member states' abatement targets according to the figures in Appendix 1. These targets will be further implemented domestically and for example Sweden has introduced a carbon tax to internalize costs of $CO_2$ emissions. (*Ibid.*)

*Renegotiation*

In the case of the Kyoto Protocol, the treaty only binds the member states to the targets of the first control period. Any adjustments or new protocols to the Kyoto Protocol require the parties to ratify the amended agreement and all the amendments should be regarded as separate agreements. Thus the Kyoto Protocol only binds the ratified member states until the end of the first control period and renegotiation is necessary to implement any further provisions. (*Ibid.*)

*Entry into force*

The Kyoto Protocol entered into force after ratification of countries accounting for 55% of the global amount of $CO_2$ emissions created by UNFCCC Annex I parties in the base year 1990 (*ibid.*).

*Treaty withdrawal*

A party to the Kyoto Protocol may withdraw at any time after three years from the date on which the Protocol entered into force for the party by giving written notification. A withdrawal takes effect one year from the date of receipt of the notification, or on any later date specified in the notification of withdrawal. Any party that withdraws from the UNFCCC is also considered having withdrawn from the Kyoto Protocol. (*Ibid.* 1998.)

*Basic obligations*

The Kyoto Protocol imposes differentiated emission ceilings to parties assigning them with a required abatement level from -8 to +10 percent relative to 1990 levels and leaving developing countries with no emission limits. The specific emission limits are presented in Appendix 1.

*Compliance and monitoring*

The Kyoto Protocol introduces a compliance committee to enforce compliance of member states and requires that a country that fails to meet its emission ceiling in the first control period (during the years 2008–2012) make up for the shortfall and reduce its emissions by an additional 30% of this amount in the next control period (UNFCCC 2004). Any new emission limits must, however, be approved by amendment, which is essentially a new treaty. Since any party to the Kyoto Protocol could decline to ratify the subsequent amendment, it can avoid being punished for defecting. In other words, there is no mechanism in the agreement that efficiently makes the ratifying countries comply with the agreement (Barrett 2002).

### 2.3.4 Project-based mechanisms

Three project-based mechanisms were introduced to the Kyoto Protocol in COP7 in 2001 in order for the members to meet the strict targets more flexibly. Member countries may invest in clean development mechanism projects for emissions reductions in developing countries, develop programs for joint implementation in Annex I countries and engage in emissions trading in order to adjust their target level of abatement. I briefly introduce these mechanisms in below.

*CDM*

The Clean Development Mechanism (CDM) allows Annex I countries to invest in "clean" projects in non-Annex I countries to gain emission credits. These "clean" projects may reduce emissions or absorb carbon through afforestation or reforestation activities. The credits are given as Certified Emission Reductions (CERs, tCERs and lCERs), which are expressed in tons of carbon dioxide equivalent as all other Kyoto accounting units. The financing Annex I country can use the credits to offset its own emissions of greenhouse gases or sell them to another country in need of credits. In addition to the positive effects of technology transfer to the developing countries, the CDM increases investment to the developing countries, which may promote the development of their economies in general. The CDM is open for the private and public sectors in all member countries and anyone can propose a project to the CDM executive board. An acceptable proposal must be environmentally sound, satisfy the CDM executive board and meet the host country's criteria for sustainable development. (UNFCCC 2004.)

*JI*

Joint Implementation (JI) works in the same way as the CDM, but in JI, both participating countries are Annex I parties and have emissions targets under the

Kyoto Protocol. Joint Implementation provides for the Annex I parties to implement projects that reduce emissions or remove carbon from the atmosphere in other Annex I parties. Under Joint Implementation the parties receive Emission Reduction Units (ERUs) that may be used as CERs in order to offset emissions of greenhouse gases (UNFCCC 2004). If an Annex I party observes a lower marginal abatement cost in another Annex I country, it will have an incentive to engage in joint implementation in order to gain ERUs for increasing domestic emissions. (*Ibid.*)

*Emissions trading*

Emissions trading is a global market for emissions units in the form of Assigned Amount Units (AAUs), Removal Units (RMUs), ERUs, CERs, tCERs and ICERs. It allows Annex I parties to acquire units from other Annex I parties. The acquiring party is allowed to increase domestic emissions and in turn the seller must abate more than set in the targets. If one country's marginal abatement cost is higher, it will have an incentive to buy permits from a country with a lower marginal abatement cost and to equalize the marginal costs across all Annex I countries. (*Ibid.*)

The goal of these mechanisms is to unify the marginal cost of emissions reduction across all parties to the Protocol in order for them to achieve the targets more flexibly and with the lowest possible cost.

### 2.3.5 Recent developments[3]

Together with the 11th Conference of Parties held in Montreal in November 2005 was also held the first Meeting of the Parties (MOP) to the Kyoto Protocol. The conference discussed various issues related to the UNFCCC and the Kyoto Protocol and among the most important issues, initiated negotiations for future actions to combat climate change under the framework convention on climate change.

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[3] The information in this section is from the UNFCCC website (2006).

COP11 founded an agreement to launch negotiations under the broader Framework Convention on Climate Change including some non-signatories to the Kyoto Protocol, most important of these being Australia and the USA. At the insistence of the USA delegation, the agreement states that the negotiations "will take the form of an open and non-binding exchange of views, information and ideas [...] and will not open any negotiations leading to new commitments".

Other decisions were also made that outline the way to future international action on climate change. Under the Kyoto Protocol, the process for future commitments beyond 2012 got underway when a new working group was established to discuss future commitments for developed countries for the period beyond 2012. It began its work in May 2006 and will expectedly attempt to set more stringent abatement targets to the Annex I countries.

Technological development was at the center of the discussions in COP11 on efforts to reduce emissions and adapt to climate impacts. The parties agreed on further steps on promoting the development and transfer of technologies. A technology that raised particular interest was carbon capture and storage, a technology that involves storing carbon underground. It is estimated to have the potential to reduce the costs of mitigation by up to 30 percent from the present. The discussion on carbon capture was based on the special report of IPCC (2001). Parties agreed to move forward with deeper analysis of this technology.

COP11 also confirmed adoption of the Marrakech accords (UNFCCC 2002), the rulebook of the Kyoto Protocol containing details on the project-based mechanisms, compliance and adaptation to climate change under the Kyoto Protocol.

In August 2006, the UNFCCC secretariat awarded a contract to build the electronic infrastructure required for settling emission trades under the Kyoto Protocol, the International Transaction Log (ITL). The ITL will be connected to the emissions trading registries of all the industrialized countries that sign up to the Protocol and is scheduled to become fully operational establishing emissions trading by April 2007. (*Ibid.* 2006.)

## 2.4 Asia Pacific Partnership on Clean Development and Climate

The Asia Pacific Partnership on Clean Development and Climate (APPCDC) is an international non-treaty agreement between Australia, India, Japan, the People's Republic of China, South Korea, and the USA. The cooperation was announced in July 2005 at the Association of South East Asian Nations (ASEAN) Regional Forum meeting and the agreement was launched on January 12 2006 at the Partnership's Ministerial meeting in Sydney. Ministers from participating countries agreed to cooperate on development and transfer of technology that enables reductions of greenhouse gas emissions. They agreed on a Charter (APPCDC 2006a) that provides the framework and structure for cooperation, a *Communiqué* (*ibid.* 2006b) that highlights the key outcomes of the meeting and a Work Plan (*ibid.* 2006c) that maps out an agenda for the taskforces in the near future. The APPCDC is consistent with the efforts of the United Nations Framework Convention on Climate Change and the aim of the agreement is to complement, rather than replace, the Kyoto Protocol (*ibid.* 2006b).

The current member countries account for about 50% of the world's greenhouse gas emissions, energy consumption, GDP and population. Unlike the Kyoto Protocol with legally binding limits to greenhouse gas emissions, the non-legally binding APPCDC allows member states to individually set their targets for reducing emissions, with no mandatory abatement targets or enforcement mechanism. (*Ibid.* 2006a.) This has raised criticism by some uninvolved states and environmental groups as the agreement is obviously regarded inefficient with no enforcement.

### 2.4.1 Current status and obligations

According to the Charter (*ibid.*), the intent is to create a voluntary, non-legally binding framework for international cooperation to promote the development and transfer of technologies and practices. The agreement is described as a forum for exchanging experiences from national development and energy strategies and an initiative for concrete and substantial cooperation. Under the agreement, the parties are expected to develop, deploy and transfer existing and emerging clean technology; meet increased energy needs and explore ways to reduce the greenhouse gas intensity of economies and build human and institutional capacity to strengthen the cooperative efforts while seeking ways to engage the private sector.

### 2.4.2 Agreement design

Since the APPCDC is essentially a voluntary non-treaty agreement, many basic qualities of IEAs are not applicable to the agreement. For example, negotiations have taken place in order to agree on the mechanisms and goals of the agreement, but these negotiations are not strategic in nature since the outcome imposes no restrictions or responsibilities to negotiating partners. Also, such an agreement text as the APPCDC charter is easy to agree on, as it is not legally binding.

*Implementation*

The implementation of APPCDC is to take place through development, diffusion, deployment and transfer of environmentally cleaner technologies and practices with a view to enable significant reductions in greenhouse gas intensities while promoting economic growth. Areas for mid- to long-term collaboration may include hydrogen, nanotechnologies, advanced biotechnologies, next-generation nuclear fission, and fusion energy. (APPCDC 2006a.) The implementation is voluntary as the partnership is non-binding and thus also the means of implementation are in the hands of member states.

### 2.4.3 Recent developments[4]

The Partnership's Ministerial meeting held in Sydney on 11 and 12 January 2006 established eight government and business taskforces on 1) cleaner fossil energy, 2) renewable energy and distributed generation, 3) power generation and transmission, 4) steel, 5) aluminum, 6) cement, 7) coal mining and 8) buildings and appliances. These taskforces are supposed to set detailed action plans to develop sustainable

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[4] The information in this section is from the APPCDC website (2006)

solutions to shared challenges through bottom-up practical action involving the private sectors, research communities and governments to drive sustainable development outcomes across partners' economies. The workgroups will bring together experts and leaders from the public, private and research sectors to share experiences on related issues.

## 3 Game theory in international environmental cooperation

The background for many studies on international environmental agreements lies in the theory of multilateral agreements. International environmental agreements represent a special case of multilateral agreements with some special qualities, but the approach of game theory is similar to the broader theory of multilateral agreements.

Pareto-optimality defines an allocation of resources where no movement from one allocation to another making at least one individual better off can be made without making any other individual worse off (Fudenberg and Tirole 1991).

The underlying game in international environmental agreements is usually assumed to be a *Prisoners' Dilemma* and lead to the free rider's problem and the so-called *Tragedy of the Commons*. In the *Prisoners' Dilemma*, two players try to receive benefits by cooperating with or betraying the other player. Cooperating is strictly dominated by defecting, so that the only possible equilibrium for the game is for all players to defect even though each player's individual benefit would be larger if they all played cooperate. (Dresher 1961.)

This result to the *Prisoners' Dilemma* also represents the *Nash-equilibrium,* where each player's strategy maximizes his payoff when other players stick to their strategies (Nash 1951). Thus, it represents a solution to the game where all the players are better or as well off as in any of their other feasible strategy spaces against the other players chosen strategies. Since the *Prisoners' Dilemma* seems to lead to a socially inefficient equilibrium, the incentives for negotiating parties must be restructured to change the outcome of the negotiation game.

Some effort has been put in cooperative games research. Chander and Tulkens (1997) show that the core of the game is non-empty and thus the potential benefits induce the formation of a coalition to share the benefits from cooperation. They conclude that full cooperation and efficiency can prevail, not as a *Nash equilibrium* but a *Lindahl equilibrium*. This suggests that the provision of public goods reaches equilibrium when all parties concerned agree on the level of goods to be provided, and their prices. In the *Lindahl equilibrium*, individuals pay for the provision of a public good according to their marginal willingness to pay and the Lindahl price is the resulting tax a citizen pays for his or her share of the public goods. (Lindahl 1958). Thus in the *Lindahl equilibrium*, all the parties to the IEA agree on abatement targets and the total level of abatement. Also Uzawa (1997) shows that under specific assumptions the core corresponds to the *Lindahl equilibrium*.

In cooperative games, the analysis concentrates on the target function of the coalition of the countries and the aim is to maximize the total net benefits to the coalition (Carraro and Siniscalco 1998). Since this study aims to examine the incentives of sovereign states, the underlying assumption of cooperation doesn't serve the purpose well and thus I focus on non-cooperative game theory.

In non-cooperative games the objective of each player is to maximize its own welfare and the equilibrium depends on all the players' choices. From the 1990s, the experiments described in the literature of non-cooperative games have been trying to understand the mechanism behind coalition formation and the possibilities to increase social welfare by different mechanisms and strategies also seen in the latest international environmental agreements (Carraro and Siniscalco 1998).

The main body of game theoretic literature on IEAs agrees that the number of signatories in stable coalitions is very limited due to the strong free riding incentives. Many studies also show that only agreements with vague and general targets that are easily reached are signed by a large number of countries (Hoel and Schneider 1997, Barrett 2003). However, some of the recent studies (Carraro and Siniscalco 1993, Heal 1994, Ecchia and Mariotti 1997) have shown that the number of signatories in a stable coalition may be increased by expanding the consideration with different assumptions or by changing the rules of the game to achieve several other equilibria.[5]

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[5] See section 3.2.

Some studies (Bloch 1997, Carraro and Siniscalco 1998, Asheim *et al.* 2005) also show that numerous regional agreements may be able to bind more parties than one global agreement.[6] These approaches may be used to study the establishment of international environmental agreements.

International environmental agreements have been modeled as two substantially different types of non-cooperative games in the recent literature. I first describe reduced form stage games and dynamic games in theory and later in sections 4 and 5 concentrate on analyzing IEAs based on quota management and technological cooperation in the light of this theory. In section 6, I consider different proposed ways to expand the stable coalitions reached by quota agreements or technological cooperation.

### 3.1 Reduced form stage games

A popular approach is to analyze the agreements as non-cooperative static games with two stages. The game is modeled as a normal form game i.e. all players decide simultaneously in both stages. In the first stage the countries play a *coalition game*, where they decide independently whether or not to join the coalition. In the second stage, the parties to the agreement play an *emission game,* where they act as a single player and divide the resulting payoff among themselves. The game is solved by backwards induction so that each player decides whether or not to join the coalition anticipating the outcome of the following emission game. This approach is used in several reduced form stage game studies (Hoel and Schneider 1997, Carraro and Siniscalco 1998, Barrett 2003). Further assumptions are:

- Only one agreement is proposed to the players
- When defecting from the coalition, any country may assume that all other countries remain in the coalition
- Each country's payoff function increases monotonically with respect to the coalition size

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[6] see section 6.4.

These are quite restricting assumptions and they have been relaxed in more recent studies. Specifically, the first one dictates that two or more regional coalitions may not coexist, which restricts the outcome to just one global agreement. The second assumption defines that the actions of one agent will not affect those of any other agents, but it is quite obvious that in reality any actions of the players may have an impact on the actions of the other players. In some dynamic game theoretic studies, this assumption has been replaced with the assumption that as a penalty from defecting, all other signatories defect in the next period. This is further discussed in section 3.2. The third assumption is also relaxed in other studies and it can be shown that in some cases other types of concave functions are more appropriate indicating diminishing individual benefits from a high level of cooperation. (Carraro and Siniscalco 1998.)

In addition to the basic assumptions, the proposed agreement must satisfy the profitability and stability conditions in order to prevail and remain stable. The profitability of the agreement to all signatories requires that the profits of each cooperating country exceed its potential profits when no countries cooperate. This may be written as:

$$P_i(s) > P_i 0 \,,$$

where $s$ denotes the coalition, $P_i(s)$ are the profits of country $i$ in the coalition and $P_i 0$ are the profits of country $i$ with no cooperation. (*Ibid.*)

The profitability condition is usually fulfilled unless there are leakage effects or large asymmetries between the countries. Unfortunately this is exactly the case in climate change mitigation; the cost of abatement varies across the countries and the differences between the costs are large enough to make international environmental agreements unprofitable to some countries.

The costs from abatement may be quite accurately modeled as costs from technological research and development to create environmentally friendly technologies and costs from reducing production. The benefits from abatement are however more abstract and it is often impossible to define the economic impact of environmental damage. Thus this approach is strictly theoretical as it models the formation of coalitions with perfect information on the costs and benefits.

In order for the coalition to remain stable, Carraro and Siniscalco (1998) define limits to the signatories' profits inside and outside the coalition. There are two stability conditions, i.e. internal and external stability. The *internal stability* condition defines that there is no incentive for the signatories to the agreement to free ride. This can be formalized as:

$$P_i(s) > Q_i(s \mid i)$$

for each country, where $Q_i(s \mid i)$ is country $i$'s payoff when it defects from coalition $s$ and $P_i(s)$ is the payoff from remaining in the coalition. This implies that every signatory country's profits are lower outside the coalition and it has no incentive to defect and free ride. Also, if any single signatory would defect from the agreement, it would be rational for the remaining members to reduce their abatement efforts and this would eliminate the free riding profits of the defecting country.

The *external stability* condition requires that there is no incentive to broaden the coalition and may be formalized as:

$$Q_i(s) > P_i(s \cup i)$$

for all countries $i$ that do not belong to $s$. This implies that profits $Q_i(s)$ for every country outside the agreement are higher than the profits $P_i(s \cup i)$ as a result from joining the coalition, indicating that no free riders would be better off after joining the coalition.

Together these three conditions define that there is an incentive to form a coalition and that this coalition is stable. These assumptions are essential to the formation of an agreement and it seems obvious by intuition as well as theory that they must hold for any stable coalition. The profit functions are a great simplification of a number of elements that affect the member states' profits in different scenarios. The agreement design defines in essence the individual profits to member states from joining or the coalition or staying outside and defecting or complying. The details are discussed below.

The limits to cooperation are usually defined as business as usual and the social optimum. The business as usual -scenario describes the situation with no cooperation or coordination in abatement. With a competitive market and no realization of pollution damage, all firms' emissions are defined by optimal profits not including environmental cost. In the case of no IEA, but with a global realization of pollution damage, game theory predicts that each country chooses its optimal abatement level given all the other countries' choices. The equilibrium solution to the pollution game can now be found by equating marginal abatement cost to marginal pollution damage for each country (Ioannidis *et al.* 2000). This case represents the *Nash equilibrium* of the game and shows that even with no cooperation in abatement, each country has an incentive to reduce their emissions from the business as usual levels.

However, according to theory, the non-cooperative *Nash equilibrium* does not necessarily achieve collective efficiency and cost minimization. This is why the literature is trying to find a sustainable equilibrium where a coalition of countries chooses the collectively optimal abatement level and non-signatories act individually rationally to maximize their payoffs. The upper limit to cooperation is defined as the social optimum, a solution that can be interpreted as the outcome dictated by a benevolent social planner with perfect information (Golombek and Hoel 2005).

A shared insight by a majority of the literature is that a globally binding agreement may only be established with minimum gains from cooperation. In this case there is also little need for an agreement since the outcome would be nearly the same with no cooperation. (Barrett 1999.) It is also not obvious that the social optimum would require global cooperation and some studies suggest that several regional agreements would Pareto-dominate a globally binding agreement. I study the different suggestions more closely in section 6.

The model in reduced form stage games is often a three-player normal form game from which the results are generalized to describe the formation of coalitions with a number of players. This method only reveals the incentives for the basic three-player game and is far too simple to catch the actual incentives for various different countries. It is difficult to derive a game theoretic model that would accurately describe the real world and many restricting assumptions are usually made.

What makes climate change a special case in environmental issues is that greenhouse gases are essentially a stock pollutant meaning that the damage caused depends on the total stock of greenhouse gases in the atmosphere rather than the flow of emissions at a given time. This is why time should be introduced into the benefit function (Ioannidis *et al.* 2000). The concept of time is included in the model in dynamic games discussed below.

### 3.2 Dynamic games

The previous approach with two stages describes a situation where there are only two decisions to take: Whether to join the coalition or not and how to divide the resulting payoff. It is, however, clear that in practice the players will have to weigh the profitability of the agreement continuously as they can defect or join the coalition at any time. This is why we should study the coalition game as a repeated game. Another reason to study repeated games is that this approach allows for the use of threats that may stabilize the agreements. When a game is infinitely repeated, it will become a dynamic game with an infinite number of stages and an infinite time frame. This is the approach of most modern game theoretic research in economics.

First I introduce some of the basic concepts of dynamic games applied to IEAs. In order for the agreement to remain stable, it must be individually and collectively rational. *Individual rationality* implies that none of the agents may improve their welfare by deviating from their equilibrium strategy. Thus the agreement must be either effectively enforced or self-enforcing. The previous assumption is usually disregarded in theory since there is no international authority that would be able to reliably enforce any global agreement.

In practice, typical enforcement mechanisms allow for the member states to report their own implementation of the IEA. To be self-enforcing, the agreement must contain a mechanism to penalize defection. Only a self-enforcing or an effectively enforced agreement can achieve stability as otherwise countries would have an incentive to cheat in order to raise their profits while apparently complying with the agreement. This would result in high participation, but abatement levels approaching the *Nash equilibrium* as the profit $Q_i(s \mid i)$ would rise for all countries that cheat.

If the members to an individually rational agreement deviated from cooperation, it would be in the best interest of the compliant countries to punish the deviator by imposing higher costs than from cooperation and thus none of the agents would want to deviate in the first place. (Barrett 1999.) The reasoning in dynamic games broadens the concept of the previously introduced stability conditions in reduced form stage games and when the notion of punishment is added, this ensures that stability remains in the infinite time frame.

*Collective rationality* implies that an equilibrium strategy must be renegotiation-proof *i.e.* an alternative agreement may not exist, that all signatories would prefer to the equilibrium agreement. This also means that if any of the signatories defect from a renegotiation-proof agreement, all the remaining members of the coalition will have an incentive to carry out the defined punishment instead of renegotiating the agreement, carrying out any other punishment or no punishment at all. (Farrell and Maskin 1989.)

With regard to the stability functions in the reduced form stage game, this implies that the cost from the punishment is built in the profit functions and the profit from complying remains larger than that from defecting in the long run even when the punishment is carried out. These rationality conditions correspond to the previously introduced stability conditions of reduced form stage games and basically translate these to the dynamic setting.

In dynamic games, the depth of cooperation is usually derived from these constraints of individual and collective rationality. However, even these basic assumptions are not always apparent in practice and even further assumptions have to be made to model the game in theory. Thus the results can only be regarded as very general as in practice many other issues have an impact on the actual outcome of negotiations.

## 4 Abatement quotas in climate change management

A quota in international environmental agreements refers to a limit or a target designated in units directly related to the environmental problem at hand. The quota may be presented as a figure or as shares of a total limit. Quotas may stand alone as an instrument to achieve the environmental objectives or they may form a basis to be combined with other instruments. (Wolf 2001.)

The Kyoto Protocol offers a good example of an IEA with abatement quotas for climate change management. The Protocol sets quotas for the emissions of developed countries setting no restrictions to the emissions of the less developed countries. In addition to the quotas defined in tons of carbon dioxide emissions, the Kyoto Protocol exhibits three mechanisms for efficient division of abatement efforts throughout the participating countries. The quotas are planned to correspond to the initial environmental status of the participating country and the mechanisms along with the initial abatement quotas determine how the costs of abatement are divided among the countries.

The Kyoto Protocol has however been criticized for not including linkage to technological issues (Barrett 2003, Golombek and Hoel 2005). Still, even an agreement based on emission reduction quotas will provide some technological spillovers through informal networks, journals and sometimes through the import of goods developed with the new technology (Golombek and Hoel 2005). Specifically, in the case of the Kyoto Protocol technological spillovers are also created by JI and CDM projects[7] and thus it should not be regarded as a pure quota management agreement.

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[7] See section 2.3.4.

The basic cases of games introduced in section 3 essentially describe games where the participating countries first agree on participation to an agreement and then on emission reduction quotas within the coalition. Reduced form stage games usually end the consideration here while dynamic game studies assume infinite following stages where the parties to the agreement decide whether to comply with or defect from the agreement. I first consider some studies on quota management in international environmental agreements and then analyze the efficiency of the Kyoto Protocol in the light of this theory.

### 4.1 Optimal agreements with emission quotas

Finus and Rundshagen (1998) present a model with an emission reduction quota, where each country has to reduce its emissions by the same percentage from the initial situation. They further assume that all countries participate in the agreement and each country derives its proposition of emissions reduction percentage from its perception of environmental damage. They consider two optional scenarios. In the first one, the negotiating countries try to find a solution that all parties could accept and in the second scenario, the countries with the highest perceived damage strive to reach an agreement between a subgroup of the negotiating countries.

They find that in the first scenario, the lowest common denominator -rule induces the negotiating countries to tell the truth about their preferences as a dominant strategy. As a conclusion, they present that the pure quota management scheme leads to a Pareto-improvement to the non-cooperative equilibrium, but falls short of the aggregate benefit from the social optimum. This is because the negotiations for quotas lead to cost inefficiency as an effect of the lowest common denominator -rule.

In the second scenario, i.e. when smaller coalitions may emerge, Finus and Rundshagen (1998) find that the degree of optimality is higher than in the equilibrium of the grand coalition. Even in this case, however, the gains from cooperation are relatively small and the social optimum is not reached as an equilibrium solution. This result suggests that the total benefit from partial cooperation may be higher than from global cooperation if the differences in damages are large between the countries. This is often the case in real world international environmental agreements as the damages perceived by the industrialized countries are relatively high compared to those of the developing countries.

The study implies that the social optimum cannot be reached as an equilibrium solution in quota management agreements. International cooperation appears to be an improvement to the non-cooperative equilibrium, but only second-best results are stable.

Finus and Rundshagen (1998) repeat their study under a dynamic framework and weakly renegotiation-proof equilibrium meaning that there is no feasible agreement that would be strictly preferred by all agents to the original agreement. They find that only second-best solutions are stable and the social optimum may not be reached with pure quota management agreements when using a reasonable assumption of a discount factor. This result is consistent with their findings in the reduced form stage framework and implies that pure emission quota agreements fall short of the social optimum while stable coalitions seem to emerge as second-best solutions.

Barrett (1999) examines the depth of international environmental cooperation with the two assumptions of individual and collective rationality in a dynamic game framework with the assumption of an underlying *Prisoners' Dilemma* game and shows that a strategy of getting even satisfies the individual and collective rationality constraints. The strategy of getting even requires that a country plays cooperate unless it has played defect less often than any of the other players in the past ensuring that the agreement is self-enforcing. The main result is that full cooperation may only be sustained when the amount of cooperating parties is small or when the gains from cooperation are small in relation to the non-cooperative equilibrium. Otherwise the agreements are sensitive to renegotiation and will not be stable in a dynamic setting.

Asheim *et al.* (2005) analyze IEAs with a simple dynamic game theoretic model, where a contract is agreed on in the first stage and enforced in subsequent stages. The problem, as in reduced form stage models, is to prevent free riding by restructuring incentives so that it is in every agent's best interest to act in compliance with the agreement. Also Asheim *et al.* (2005) incorporate the assumption of collective rationality as renegotiation-proofness to find that cooperation may improve the benefits from the non-cooperative equilibrium and two regional agreements seem to Pareto-dominate only one global agreement. This study is discussed further in section 6.4.

These dynamic game theoretic studies seem to reach similar conclusions with the previously discussed research based on reduced form stage games. The stable coalition appears to improve the non-cooperative *Nash equilibrium*, but the social optimum cannot be reached with pure quota management. Also, the stable is only stable with a small amount of cooperating parties or with small gains from cooperation.

## 4.2 Kyoto Protocol and quota management

In this section I study the optimality of the Kyoto Protocol in the light of the theory and analyze its optimality in climate change mitigation. The Kyoto Protocol to the UNFCCC defines initial abatement targets for all the Annex I countries.[8] The abatement targets are based on the assigned amounts of emissions to all the parties to the Kyoto Protocol and the targets cover emissions of the six main greenhouse gases.[9]

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[8] These targets are presented in Appendix 1.

[9] Carbon dioxide ($CO_2$), Methane ($CH_4$), Nitrous oxide ($N_2O$), Hydro fluorocarbons (HFCs), Per fluorocarbons (PFCs) and Sulphur hexafluoride ($SF_6$).

The emission quotas are negotiated in the Conferences of Parties and all the participating countries must accept the suggested quotas by ratifying the agreement before the agreement becomes binding. Since participation to the agreement is voluntary and the initial coalition is formed as a result from multilateral negotiations, the process corresponds closely to the one introduced by Finus and Rundshagen (1998). The minimum participation clause in the Kyoto Protocol has somewhat reshaped the negotiations as the first ratifying parties had a guarantee of the minimum size of the coalition (Barrett 2003), but apart from this, the negotiations did not exclude any type of coalition or even numerous coalitions from being formed. Thus the Kyoto Protocol is a good example of a quota management agreement as a majority of the incentives are shaped by the distribution of initial abatement quotas.

The Kyoto Protocol introduced three project-based mechanisms to optimize the abatement costs across all the countries and these mechanisms should guarantee that the marginal abatement cost is equal in all the parties to the Kyoto Protocol. However, the design of the emission targets and mechanisms complicate this assumption. Since there are no targets for the developing countries and only a limited number of CDM projects can be implemented, it is likely that the marginal abatement costs will not be equal across all the countries. Emissions trading should guarantee that the marginal cost is equal in all the Annex I countries, but inequality in abatement costs may remain between the developed and developing countries as the project-based mechanisms are supervised by an international board with authority to issue credits for projects.

Barrett (2003) criticizes that the management of CDM projects may create the problem of “paper trades”. Since most projects in developing countries provide cost reductions compared to emission reductions in the Annex I countries, the executive board may accept projects that do not achieve the required benefits in emission reductions. The benefits of emission reductions are difficult to measure and since there are no limits for the emissions in developing countries, it may be argued that bad governance of CDM projects will only provide the industrialized countries with access to cheaper emission credits through CDM projects. In the meanwhile the developing countries may still increase their emissions without limits.

It is not obvious that the profitability condition is fulfilled for all cooperating parties in the Kyoto Protocol. The total profit essentially depends on the environmental damage from climate change and there are very diverse conclusions on the impacts of climate change (IPCC 2001, ABARE 2006). The current coalition structure is based on very general estimates of benefits and damages. For the same reason, the external stability of the coalition may not be attained as some non-participants may in fact have an incentive to accede to the agreement. As discussed in section 2.3.3, the Kyoto Protocol doesn't efficiently address incentives to free ride thus risking the internal stability of the treaty. Any new emission limits must be approved by amendment and the penalty imposed on the defecting parties doesn't necessarily ensure stability (Barrett 2002).

The Kyoto Protocol doesn't seem to meet the terms of individual and collective rationality in the dynamic framework either. By imposing a penalty for defection, the Kyoto Protocol addresses the issue of individual rationality, but in order to be stable in the long run, the agreement must be either effectively enforced or self-enforcing. The compliance committee discussed in section 2.3.3 may be able to enforce the agreement efficiently, but the penalty from defection does not ensure strategic incentives to cooperate and make the agreement self-enforcing. Also, it is not obvious that the Kyoto Protocol is renegotiation-proof as the information on benefits and damages varies in time changing the incentives of the negotiating parties.

These are not necessarily fundamental flaws in the Kyoto Protocol as many of the shortfalls are result from imperfect information and uncertainty of the future. It seems however that the agreement design does not provide efficient strategical incentives for compliance and the profitability of the quota management regime is not optimal to induce participation.

## 5 Technological cooperation in climate change management

Until now I have concentrated on different kinds of quota management agreements and other methods of climate change management have been raised only as issues linked to the quota-based agreement. In recent literature (Barrett 2002, Buchner *et al.* 2002, ABARE 2006), technological cooperation has also been offered as a separate option to quota management in climate change policy. The essence of technological cooperation lies in the exchange of environmentally friendly technologies through direct technology transfer and cooperation in projects involving new technologies.

There are few examples of pure technological cooperation in IEAs, while R&D cooperation is often linked as an issue to more common agreements with emission quotas or emission taxes (Barrett 2003). Technological cooperation has still been studied in theory and as a current example, the APPCDC initiative aims to combat climate change without emission quotas or taxes by pure technological cooperation. The Kyoto Protocol does not require any cooperative funding for R&D and most participating countries have in fact cut down their R&D funding since the introduction of the Kyoto Protocol (*ibid.* 2002). In this light, the two approaches represent highly diverse ways to combat climate change. In this section I present some current studies on pure technological cooperation and technological issue linkage in IEAs and consider the APPCDC initiative in the light of this theory.

### 5.1 Optimal agreements with technological cooperation

Barrett (2002) answers the problems of weak incentives to participation and compliance in the Kyoto Protocol by suggesting a model of technological cooperation with an agreement that supports development of new clean technologies by cooperative funding and sets protocols for the adoption and diffusion of these new technologies. He suggests that this kind of an agreement would create push incentives in the form of cooperative funding to R&D and pull incentives as benefits from the technological innovations instead of the mere pull effects in quota management agreements as incentives to create environmentally clean technologies.

According to Barrett (2002), an agreement based on technological cooperation would not require enforcement for compliance and it would provide positive incentives for participation as the diffusion of technology standards in some countries create incentives to the other countries to adopt the same standards. Some of the benefits from the agreement would depend strictly on participation to the agreement as such benefits could be excluded from non-participants for example with patents and research joint ventures. He suggests that an agreement based on technological cooperation could provide a more efficient second best alternative than a quota agreement of the Kyoto type.

Buchner *et al.* (2002) use an ECT-RICE[10] -model, a single sector optimal growth model based on dynamic game theory to study the economic and environmental effectiveness of technological cooperation in climate change mitigation. The RICE model introduced by Nordhaus and Yang (1996) is extended to incorporate the interactions between economic activities and climate to derive numerical simulations of the changes in emissions as a result from pure technological cooperation. The model also incorporates endogenous technical change to catch the effect of technological advance to factor productivity and induced technical change to allow for the stock of knowledge to affect the emission-output ratio. To simulate the impact of international cooperation, technological spillovers are also modeled.

Buchner *et al.* (2002) find that whenever there are relevant excludable benefits from cooperation, all countries cooperate in a stable and profitable coalition. Such excludable benefits are also realistic as in a regime based on cooperative funding and controlled diffusion of technological advances, members of the coalition receive more benefits than non-participants. The study reveals no incentive to free ride on technological cooperation since the economic benefits can be excluded from non-participants. This confirms Barrett's (2002) finding that technological cooperation creates strong incentives for participation.

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[10] Regional Integrated model of Climate and the Economy (RICE); Endogenous and induced Technical Change (ECT).

However, Buchner *et al.* (2002) also find that the global aggregate emissions as well as the emissions per unit of output would rise if a technological agreement were adopted instead of the current coalition of the Kyoto Protocol. They conclude that aggregate production would increase as a consequence of the intensified R&D efforts and this would raise the emissions of countries that cooperate on R&D. Emissions per unit of output would also increase because the overall impact of accumulated R&D expenditure on economic growth would be larger than the impact on emission abatement. This conflicts with Barrett's (2002) results and shows that the environmental benefits from pure technological cooperation may be lower than under a pure abatement quota agreement.

Golombek and Hoel (2005) examine quota- and tax-based agreements when there are technology spillovers within and across countries, and the technology externalities within each country are corrected through a domestic subsidy of R&D investments. They incorporate a simple static framework ignoring the fact that GHG emissions are stock pollutants and neglecting the dynamic aspects of R&D. They also consider only one type of greenhouse gas, namely $CO_2$, and disregard all types of uncertainties, like the rate of return on R&D investments, and assume that all countries are identical. Thus the results also give only a very general insight to the issue.

The results from Golombek and Hoel's (*ibid.*) study suggest that with international spillovers, there is a social loss from not including R&D policies in an international climate agreement even when monitoring of compliance of the R&D efforts is imperfect. This implies that it is beneficial to include technological issues in an agreement whenever there are positive international spillovers from technological progress. They suggest that a pure quota management agreement may reach optimal abatement levels, but will encourage inefficiently low R&D investments relative to abatement efforts. As a result, the short-term abatement efforts may be optimal with mere abatement quotas, but the long term global abatement level will be below the optimum that could be reached with a higher level of technological development.

The results above suggest that a technological agreement might be able to induce all countries to cooperate, thus also making issue linkage more efficient. While Barrett (2002) suggests that technological cooperation could result in lower emissions than an agreement based on abatement quotas, Buchner *et al.* (2002) note that emissions of countries that cooperate on R&D would rise as a consequence of the intensified R&D efforts. They suggest that a combination of technological cooperation and quota management would provide lower aggregate emissions than any of the two measures separately and Golombek and Hoel (2004) agree that there are aggregate benefits from linking technological cooperation to quota agreements. Since technological cooperation increases R&D efforts within countries, as well as growth and welfare, it should be possible to link other policy issues to the agreement to redirect some of the benefits from growth back to the environmental issue at hand. These results support the hypothesis of this study that a combination of quota management and technological cooperation could induce higher social benefits than any of these measures alone. Technological issue linkage is further discussed in section 6.2.

## 5.2 Asia Pacific Partnership on Clean Development and Climate and technological cooperation

The intent of the Asia Pacific Partnership on Clean Development and Climate is to create a voluntary, non-legally binding framework for international cooperation to promote the development and transfer of technologies and practices. The parties to the non-treaty agreement are expected to develop, deploy and transfer existing and emerging clean technology. The agreement will not impose binding restrictions or create collective funding for supporting technological innovation.

This is an essential notion of the theoretical approach above as only cooperative funding of R&D projects and binding agreements on technological diffusion will be able to create strong incentives for cooperation. Without control on diffusion it cannot be effectively coordinated where the spillovers from technological progress are directed and with no cooperative funding, the push effect of technological cooperation is lost.

In fact the approach of the APPCDC will not restructure any incentives since even without the initiative the involved countries are free to exhibit voluntary technological cooperation. With no restructuring of incentives, the R&D efforts will concentrate on areas with the least spillovers as firms seek competitive advantage to others. Without control mechanisms, any technological cooperation will be conducted where it is most beneficial for member states and businesses and thus it will not create incentives to join the coalition. Thus the profitability condition may in fact best be described as an equality. With no restrictions and control on technological diffusion in the coalition, negotiating parties should in fact be indifferent on joining the coalition or not.

## 6 Expanding the coalitions

The main goal of the literature of international environmental agreements is to define the size of the potential stable coalition. In early non-cooperative research, the conclusion was that only small coalitions including a fraction of the world's countries are stable (Carraro and Siniscalco 1993, Barrett 1994). More recent research has provided implications of a larger stable coalition achievable by dynamic games and different assumptions for the model. In this section I study the size of stable coalitions and examine different ways to expand the initial coalition.

Barrett (2003) shows that in a reduced form stage game with a linear profit function, full cooperation may be achieved only with two players. If there are more than two players in the game, the model shows that only two of all the players play abate in the equilibrium. Substantially different results arise from differently defined profit functions. Barrett (1994) also shows by numerical simulations that depending on the specification of the parameters of the cost and benefit functions, the stable coalition may not exist at all, or it may exist consisting of only two or three signatories. Finally, he shows that the coalition may also include all players that share the resource in question when the difference of net benefit between the non-cooperative and fully cooperative outcome are small.

Interestingly, he reaches similar conclusions with a dynamic game setting, where the agreement is assumed to be self-enforcing and renegotiation-proof. Barrett (*ibid.*) shows that the full cooperative outcome may not be achieved in the dynamic setting since the punishments associated with dynamic games may be vulnerable to renegotiation. He provides simulations of the number of signatories in a dynamic game setting and derives the result that, again, the size of the coalition may only be large when the benefits from cooperation are small. Barrett's (*ibid.*) results may be biased because of strict assumptions, but it is remarkable that he derives similar results in dynamic and reduced form stage games.

The most significant assumptions in Barrett's model are that 1) all countries are symmetrical, 2) there is perfect information regarding net benefits of all countries, 3) the choice instrument is restricted to pollution abatement, 4) abatement levels are observable instantly and without cost, 5) the pollutant does not accumulate in the environment and 6) the cost functions are independent. (*Ibid.*) It has been shown (Na and Shin 1998) that symmetrical countries are more likely to form a large coalition than asymmetrical ones because their profits from cooperation are assumed equal and thus the incentives to free ride are smaller. Also, the hypothesis of perfect information in assumptions 2) and 4) are obviously unrealistic and Na and Shin (*ibid.*) show that uncertainty increases the incentives to form a large coalition. Furthermore, in the case of greenhouse gases, the pollutant accumulates in the environment, and it has been argued (Heal 1994) that in addition to this, dependence of the cost functions will increase the incentives to cooperate. These observations on Barrett's (1994) assumptions provide reason for further consideration.

Hoel and Schneider (1997) use a similar model with similar assumptions to Barrett (1994) and show that without side payments, the coalition may be small, but depending on the specification of the profit function it may also be globally binding. With side payments, the number of participants is shown to reduce if the disincentive effect of the side payments is strong. Including non-environmental cost to non-participants, the asymmetrical cost functions ensure that the countries with high cost from non-participation have an incentive to join the coalition, while the impact of asymmetry before coalition formation is disregarded. It can still be assumed that asymmetrical cost functions across all countries would result in a smaller stable coalition as suggested by Finus and Rundshagen (1998).

Hoel and Schneider's (1997) basic results are in agreement with those previously presented by Carraro and Siniscalco (1993). They show by a reduced form stage game that the size of the stable coalition essentially depends on the amount of interdependency between the countries represented by the best-reply function. The best-reply function used corresponds to Hoel and Schneider's (1997) notion of a profit function and also the results are quite similar. With negatively sloped best-reply functions, the marginal damage from foreign countries' emissions is high and non-cooperating countries expand their emissions when the coalition restricts its emissions. This prevents the formation of a large coalition since the abatement efforts by the coalition are offset by the increase in emissions of non-participants. On the other hand, with near-orthogonal best-reply functions the stable coalition may be larger, but the benefits from cooperation are low as the marginal damage from foreign emissions to participating countries is small. Carraro and Siniscalco (1993) also find that the number of signatory countries may be increased by self-financed transfers. This clearly conflicts with Hoel and Schneider's (1997) result that side payments reduce the number of participants.

Different assumptions on the qualities of the negotiating parties and conditions of the contracts may however lead to more positive results. Heal (1994) shows that by abandoning the assumption of independence or by using fixed abatement costs the incentives to cooperate are increased. By assuming dependence, he proposes that the costs and benefits from abatement depend on other countries' actions so that an increase in any one country's abatement level increases the marginal benefit and decreases the marginal cost of abatement in other countries. This sort of dependence between the players leads to higher abatement levels and reduces the free riding incentives. He shows that fixed abatement costs lead to similar results.

Ecchia and Mariotti (1997) adopt the assumption of farsightedness to allow the countries to anticipate other countries' reactions to their actions and use this information in their decisions. They also assume that non-participating countries can cooperate with respect to the original coalition. With these new assumptions they show that in equilibrium of all four games studied, full cooperation is possible while no cooperation is not sustainable as equilibrium. The logic behind the results is that the strength of the individual incentives to free ride may persuade all countries to cooperate for fear of a chain of retaliations resulting in the non-cooperative equilibrium. The analysis suggests that farsightedness increases the probability of larger coalitions because the assumption of farsightedness makes the threat of free riding more credible.

The assumption of farsighted strategic reasoning on behalf of the negotiating countries separates this study from the general direction of the research, but with perfect information it may in fact be that the actions of the negotiating parties resemble farsightedness. With information on the other countries' costs and benefits, it can be argued that they are able to make strategically farsighted choices. (Ecchia and Mariotti 1997.)

Endres and Finus (1998) add environmental awareness to the costs of the emissions in their framework and show that the total gains from cooperation rise with the level of environmental awareness for each country. It is however shown that with asymmetric countries with respect to environmental awareness, the stability of the coalition decreases with an increase in environmental awareness. The difference between the profits from the coalition and the *Nash equilibrium* grows for countries with smaller environmental awareness and they have a stronger incentive to free ride. The basic results seem to hold in reduced form stage games as well as in dynamic games but Endres and Finus (1998) find that in dynamic games a small global increase in awareness increases the stability of the coalition and a large one reduces stability while in reduced form stage games the opposite holds. This result is derived from the collective rationality constraint in dynamic games and it is shown that a large increase in awareness decreases the potential punishment to the defecting country and thus decreases stability. In reduced form stage games this "punishment effect" is not considered and this is why the results differ within the two frameworks. (Barrett 1994)

Na and Shin (1998) add an interesting element of uncertainty to the framework. It is obviously very difficult for the negotiating countries to estimate the total benefits from abatement and this is why Na and Shin (1998) include uncertainty as a random variable for the marginal benefit of abatement. With a three country model they show that the *ex ante* negotiations always lead to full coalition while *ex post* negotiations lead to partial coalition or no coalition at all. With *ex ante* expectations the countries' benefits are closer to each other than with the *ex post* realized profits and similar countries are more likely to form a coalition than highly asymmetrical countries. This is an interesting result since there always remains uncertainty about the benefits from abatement. The costs may be calculated quite accurately in the negotiation phase, but the benefits are usually revealed much later if ever and present a challenge to the negotiating countries.

These studies have attempted to explain the stability of international environmental agreements and specifically define the size of a stable coalition. With such a complicated real world problem it is difficult to define the correct assumptions for the model and it may even be that diverse assumptions should be adopted for countries depending on differences in costs and benefits as well as internal decision-making for example. As many of these studies suggest, only small coalitions seem to be stable in the basic framework and a large coalition can only be formed with minimal benefits from cooperation. Further issues such as environmental awareness, uncertainty and farsightedness seem to increase the size of stable coalitions at least in theory.

Some research has been made to include other issues that could expand the size of the initial coalition by increasing the incentives for more countries to participate in the agreement or by decreasing the incentive to cheat in implementation of the agreement. The issues considered include some measures that have also been realized in the most recent IEAs and the main approaches may be divided into four ideas after Carraro and Siniscalco (1998): 1) transfers, 2) issue linkages, 3) threats and 4) multiple agreements. I discuss these ideas in the following sections.

## 6.1 Transfers

As argued by Carraro and Siniscalco (1993), transfers have been found to be able to increase the size of the stable coalition. Initially they find that in a reduced form stage game framework, self-financed transfers cannot expand the stable coalition. However, by assuming different types of commitment to the cooperative strategy, they find that gains from partial cooperation can be used to expand existing coalitions by inducing other countries to cooperate using self-financed transfers. Transfers cannot sustain global cooperation without some degree of commitment since the transfers to non-cooperating countries create instability and an incentive for the participants to deviate. Full commitment is not required, and credible commitment of even a fraction of the countries can lead to the full cooperative equilibrium. Barrett (2003) strongly opposes the idea of commitment especially when the underlying game is assumed to be the *Prisoners' Dilemma*. He concludes that commitment is not credible whenever there is an incentive to deceive the other players. In the *Prisoners' Dilemma* it is obvious that the players have an incentive to deceive by committing to a non-equilibrium strategy.

Still, Carraro and Siniscalco (1993) are not alone with their results, as also others have found that self-financed transfers may increase the size of the coalition in reduced form stage as well as in dynamic game settings (Kaitala and Pohjola 1995). The point of transfers is that especially with highly asymmetrical countries, some countries have strong incentives to refuse cooperation while others gain more from cooperating. Some of the cooperating countries may be better off after transferring some of their benefits to the non-cooperating countries in order to motivate them to join the coalition.

Hoel and Schneider (1997) study the effect of transfers in a framework with the assumption of an asymmetrical non-environmental cost for non-participants of an agreement and find that in this setting the effect of transfers is negative. When side payments are introduced for non-participating countries, the effect of the non-environmental cost is diminished and the size of the stable coalition reduced. If the disincentive effect of side payments is strong, side payments will lead to an increase in total emissions. Even though the general result seems to conflict with Carraro and Siniscalco's (1993), they agree that transfers create instability in the absence of commitment.

By extending the study to account for asymmetrical countries, Petrakis and Xepapadeas (1996) derive similar results to those by Carraro and Siniscalco (1993). They show that if there is a group that is committed to cooperation that gains from moving from the non-cooperative equilibrium to the coalition equilibrium, they can enlarge the stable coalition by self-financed transfers. This requires that the benefits to the committed parties from the larger coalition are high enough relative to the marginal disutility to the non-participants or that the number of committed members is large relative to the number of non-participants. The new result from the study is that the countries with high damage from the emissions are likely to commit to cooperation and offer side payments to the countries with a lower environmental damage. The scope of asymmetry defines the limits for the stable coalition.

## 6.2 Issue linkages

Another way to expand the stable coalition is issue linkage that has also been realized in some IEAs in practice. Issue linkage typically refers to the case when the participation to an international agreement is linked to other issues such as trade policy, research and development, international debt or development assistance. Issue linkage connects the environmental problem with an outside issue that affects the incentives of the parties to sign the agreement. The linkage of environmental negotiations to other economic issues may be useful to reduce constraints imposed by asymmetries on the emergence of stable IEAs and to increase the size of the stable coalition (Carraro and Siniscalco 1998). Technology transfer is a frequently used issue linkage and it binds the signatories to share technological innovations with other signatories, but not with non-signatories. This linkage has an important implication to the subject of this study and is also discussed in section 5. Most of the economic literature on international environmental agreements concentrates on linkages with trade and R&D efforts (Ioannidis *et al.* 2000). These two cases are reviewed below.

Breton and Soubeyran (1997) study the interaction between the environmental and trade policies with a reduced form stage model and an assumption of asymmetrical factor endowments. Environmental and trade policies define the revenues to the agents from these endowments and the effects from different policies have different impacts on the agents' utilities. They perform simulations under different scenarios to compare the socially optimal policies with the ones that would emerge from a political process as a result of majority voting and show that there is a strong correlation between trade policy and environmental policies whenever the tradable good affects the environment.

Technological issue linkage is discussed in the article by Carraro and Siniscalco (1997) as a way of expanding stable coalitions. They consider the previously presented two-stage model with an added third stage where the local firms choose research and development expenditure knowing the results of the two previous stages, the coalition game and emissions game. In the emissions game, the local government imposes emissions limits to the firms and they maximize their utility subject to the research and development level and production level. Carraro and Siniscalco (*ibid.*) assume that technological benefits are an excludable good meaning that the R&D spillovers to a cooperating country are larger than those to a non-cooperating country. This is a reasonable assumption and also seen in practice in the Kyoto Protocol for example, where joint implementation and the clean development mechanism improve technology transfer between the cooperating countries. They also assume that the reaction functions for the two groups of countries are assumed negatively sloped. This is to catch the Cournot oligopoly effect that production in the non-cooperating countries is reduced when the cooperating countries with a lower marginal cost increase their production.

Carraro and Siniscalco's (1998) following study shows that the linkage of negotiations on environmental protection with negotiations on other economic issues increases the stability of the coalition and may increase the number of cooperating countries. The emerging coalition in their model proves to be profitable and more stable than one emerging only from environmental negotiations because it uses the gains from technological cooperation to offset the incentives to free ride. The issue linkage has four effects on welfare in the cooperating countries; 1) technological cooperation decreases the marginal costs of the firms increasing their profits, 2) by reducing the marginal cost, issue linkage increases output and raises consumer surplus, 3) the incentive to cooperate on technological issues overcomes the incentive to free ride and increases the profitability of the coalition and finally 4) the increase in output generates additional emissions. Even though the last effect is negative, the total effect on welfare appears to be positive and the linkage of the technological issues is the optimal solution to the game.

Katsoulacos (1997) criticizes the previous approach, as it doesn't allow for firms to enter joint ventures outside the combined agreement. It seems obvious that the firms can participate in such cooperation also independently and he assumes that firms cooperate individually regardless of the local governments. In his framework the governments can only promote the technological cooperation by subsidizing research joint ventures and firms are the ones who finally decide the form and level of research and development spillovers under cooperation and non-cooperation. The conclusion is that joint support for research joint venture subsidies combined with the environmental agreement may result in a first-best optimal level of emissions. The condition for this is that the benefits from unilateral subsidy transfers exceed the welfare benefits from the subsidy, while the latter benefits exceed the benefits from defecting from the environmental agreement. In this case all countries will have an incentive to support research joint venture subsidies and technological issue linkage will be sustained by all countries. (*Ibid.*)

These examples support the idea that different forms of issue linkage may increase the stability of the agreement and ideally increase the number of signatories to the agreement. Some restricting assumptions have to be made in order to model the negotiations, but even with several various assumptions, the same result is derived for both kinds of issue linkage considered above.

### 6.3 Threats

As mentioned in section 3.1, penalties from defecting from the agreement may strengthen the incentives of states to comply and eventually stabilize the coalition. Threats are also perceived to increase the number of signatories to an agreement when they are extended outside the cooperating parties. In international environmental agreements, a threat could be related, for example, to increased emissions by the complying parties, sanctions of smaller emission quotas in the future for the defecting party or possibly even more loosely related issues such as trade sanctions.

The key issue in threats is that they must be credible in order to enhance cooperation. Carraro and Siniscalco (1998) note that credible threats are difficult to design and even in the case of a stable and profitable coalition, signatories may in fact lose from carrying out sanctions thus making any threats implausible. Therefore, threats should be carefully designed to ensure they are credible and profitable for member states. Basically, any threats should comply with the definition of *collective rationality* introduced in section 3.2. If non-compliance of a member state launches renegotiation of the agreement or no action from other parties, the original agreement was obviously not collectively rational.

Threats can also be used to enlarge the coalition when imposed on all negotiating parties. Barrett (1997) considers an example of trade sanctions in goods that are related to the environmental problem as a means to expand the coalition. He notes that since punishments related to abatement hurt signatories to an IEA as well as non-signatories, substantial punishments are unlikely to be credible. In order to effectively deter free riding, the strategy space for punishing non-cooperation must be expanded to involve international trade. Environmental cooperation will typically be automatically linked to international trade.

Barrett (*ibid.*) finds that a credible threat to impose trade sanctions may be capable of sustaining full cooperation in environmental cooperation, provided the sanctions are accompanied by a minimum participation clause which serves to coordinate government behavior. In equilibrium, all parties cooperate and trade is not restricted by sanctions. Without the sanctions, the cooperation would be Pareto-inefficient and participation incomplete.

## 6.4 Multiple agreements

One of the latest findings is that several regional agreements may induce greater social welfare than one large agreement (Bloch 1997, Carraro and Siniscalco 1998, Asheim *et al.* 2005). The case of multiple agreements has been studied in the reduced form stage game framework as well as with dynamic games and the main result is the same with both approaches. It seems that allowing for a number of coalitions, the equilibrium structure that emerges from the negotiation process includes several coalitions. The results also suggest that social welfare may be higher with multiple agreements than with just one global agreement.

Bloch (1997) uses a reduced form stage model to allow the countries to negotiate more than one agreement and concludes that two coalitions define the equilibrium of the game. Following Bloch (*ibid.*), Carraro and Siniscalco (1998) study the emergence of multiple agreements in a reduced form stage game framework with the assumptions presented in section 3.1 with the exception that this time multiple agreements might prevail in the equilibrium. They conclude that several coalitions of different sizes may emerge at the equilibrium and one grand coalition may never be the equilibrium with these assumptions.

Finus and Rundshagen (2003) use a somewhat different approach to multiple agreements as they introduce the coalition-proof *Nash equilibrium* and an open membership multiple coalition game to complement the equilibrium concept and the coalition game. They analyze among other issues the existence of several agreements in the equilibrium and conclude that any equilibrium coalition structure other than the single coalition structure Pareto-dominates the case of one global agreement. Thus the possibility to form multiple coalitions increases the overall success of combating global emissions.

Asheim *et al.* (2005) introduce a simple dynamic model to compare the scenario where only one global agreement is introduced to a scenario with two regional agreements and show that two regional agreements Pareto-dominate the scenario of only one global agreement. The results are based on an underlying *Prisoners' Dilemma* and the higher payoffs are obtained mainly because of the choice of enforcement strategy. The penance strategy defines that all agents who played cooperate in the first period will always play cooperate unless any other agent plays defect. In this case all the cooperating agents will defect until the first deviating player returns to cooperation.

Evidently, in the case of two regional agreements, the cost of penance is smaller when any one player deviates from cooperation, because one coalition may resume cooperation while the other suffers environmental damage from penalizing the deviation. This makes the assumption of underlying strategy the most important point of their study. Penance is a popular theoretical assumption in the literature, but it may not be a very realistic assumption since IEAs often define individual penalties or no penalties for deviating instead of applying the strategy of penance for all deviations. The existence of two regional agreements has no impact on the payoffs if all the agents stick to their initial strategies, since the only benefit is from the smaller losses from punishment.

The existence of multiple agreements in the optimal equilibrium is supported by a majority of the research, but the underlying assumptions about the penalty for deviation, especially the penance strategy, are very strong and seem to be the main source of cost reductions with multiple agreements. Many supporting arguments have been presented for multiple and regional agreements and for example Asheim *et al.* (*ibid.*) suggest that geographical and cultural proximity, similar economic and political systems and similar preferences would promote the creation of regional agreements by reducing uncertainty and negotiation costs. These are however quite abstract notions and it is difficult to analyze their impact on the costs and benefits of the negotiating countries.

## 7 Conclusions

This study shows that an international environmental agreement based on abatement quotas can hardly achieve the social optimum of abatement because it is not able to create strong enough incentives for all the negotiating parties to join the coalition and comply with their emission quotas. Quota management creates strong incentives to free ride since the benefits from abatement are non-excludable. Cooperation seems to be restricted by the rule of the lowest common denominator and global cooperation emerges as equilibrium only with minimal environmental benefits achieved with low abatement quotas while higher abatement targets only sustain cooperation of a small subcoalition. Thus only small improvements to the non-cooperative equilibrium can be achieved by pure quota agreements and only second-best results are stable as equilibrium. The same conclusions are reached in reduced form stage as well as in dynamic game theoretic studies.

Regardless of strict assumptions and rough simplifications in theory, the results seem to relate to practice. The Kyoto Protocol to the United Nations Framework Convention on Climate Change appears to introduce far too small greenhouse gas emission reductions to have an observable impact on climate change, but still it has only induced ratification by part of the negotiating parties. The non-participation of the United States and Australia to the treaty will undermine the initial objectives of the Protocol and it may also reduce the incentives of other parties to comply.

Treaties based on technological cooperation seem to be able to induce all countries to join the coalition by creating strong individual incentives to cooperate in a regime based on cooperative funding and controlled diffusion of technological advances. It appears that whenever there are relevant excludable benefits from cooperation, all countries cooperate in a stable and profitable coalition. The assumption of excludable benefits seems realistic and there are no incentives to free ride on technological cooperation since members of the coalition can exclude non-participants from the economic benefits. However, aggregate production appears to increase as a consequence of the intensified

R&D efforts and this may raise the aggregate emissions of countries that cooperate on R&D. Some emission reduction policies seem necessary in addition to technological cooperation to provide environmental effectiveness.

On the other hand, agreements based on technological cooperation fail to create efficient cooperation in the absence of collective technological funding and control on the diffusion of the technologies as is the case with the Asia Pacific Partnership on Clean Development and Climate. Without control on diffusion, the direction of spillovers from technological progress cannot be effectively coordinated and with no cooperative funding the push effect of technological cooperation is lost. In fact, the approach of the APPCDC will not restructure any incentives, as even without the initiative the involved countries are free to exhibit voluntary technological cooperation. Without control mechanisms, any technological cooperation will be conducted where it is most beneficial for member states and businesses and thus it will create little incentive for participants to cooperate.

With regard to the size of the stable coalition, it appears that a large coalition can only be formed with small benefits from cooperation and elements that increase the benefits from cooperation usually also seem to decrease the size of the stable coalition. However, some assumptions seem to expand the stable coalition and it is argued that even a global agreement may be reached under reasonable assumptions.

The results from transfers to expand the stable coalition are quite controversial and it is not obvious if transfers can be introduced to increase the stability of the agreement. It seems clear that some degree of commitment is necessary to maintain stable coalitions with efficient transfers, but the whole assumption of commitment is arguably unrealistic, as it would require unilateral commitment to the socially beneficial strategy.

Different forms of issue linkage may increase the stability of the agreement and ideally increase the number of signatories. Some restricting assumptions have to be made in order to model the participation, but even with varying assumptions, issue linkage in technological issues and trade seem to increase the stability.

A credible threat to impose trade sanctions may be capable of sustaining full cooperation in environmental cooperation, provided the sanctions are accompanied by a minimum participation clause which serves to coordinate government behavior. The equilibrium is socially optimal when all parties cooperate and trade is not restricted by sanctions.

Allowing for a number of coalitions, the equilibrium structure that emerges from the negotiation process appears to include several coalitions. The results suggest that social welfare may be higher with multiple regional agreements than with just one global agreement.

An important result from the study is that a technological agreement might be able to induce all countries to cooperate, when also issue linkage would be more efficient. Since technological cooperation increases R&D, growth and welfare, it should be possible to link other policy issues to the agreement in order to redirect some of the benefits from growth back to the environmental issue at hand. A combination of technological cooperation and quota management may be able to create incentives for global participation together with socially efficient abatement introducing lower aggregate emissions than any one of the two measures separately.

## 7.1 Summary of the contributions

An international environmental agreement based on abatement quotas cannot achieve the social optimum of abatement because it is not able to create strong enough incentives for all the negotiating parties and the greenhouse gas emission reductions produced by the current coalition of the Kyoto Protocol seem to be far too small to have a considerable impact on climate change.

Treaties based on technological cooperation seem to be able to induce all countries to join the coalition by creating strong incentives to cooperate, but the simultaneous increase of aggregate production may raise the emissions of countries that cooperate on R&D. However, technological agreements fail to create efficient cooperation in the absence of collective technological funding and control on the diffusion of the technologies, as is the case with the Asia Pacific Partnership on Clean Development and Climate.

It seems that a large coalition can only be formed with small benefits from cooperation and elements that increase the benefits from cooperation usually also seem to decrease the size of the stable coalition. However, issue linkage may increase the stability of the agreement and ideally increase the number of signatories to the agreement. A credible threat to impose trade sanctions may be capable of sustaining full cooperation in environmental cooperation. Social welfare may also be higher with multiple regional agreements than with just one global agreement.

A combination of technological cooperation and quota management could be able to create incentives for global participation together with socially efficient abatement and lower aggregate emissions than any of the measures separately.

## 7.2 Suggestions for future research

This study has covered several issues related to climate change mitigation specially comparing regimes based on quota management and technological cooperation. The interesting finding that technological cooperation combined with quota management could Pareto-dominate any of these measures separately deserves further consideration. However, it would be difficult to create a model of such an agreement, as even models of each regime separately require broad assumptions and simplifications.

Another approach could be to study the linkage of other policy issues to the agreement to redirect some of the benefits from growth back to the environmental issue at hand following the idea of Golombek and Hoel (2004). The focus could be to develop a model of global cooperation based on technological diffusion and cooperative funding and study the limits of global cooperation with abatement quotas for member states.

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## Appendix 1

Countries in Annex B to the Kyoto Protocol and their emissions targets for the first budget period (UNFCCC 2006):

| Party | Quantified emission limitation or reduction commitment (percentage of base year or period) | Emission target under the EC agreement (percentage of base year or period) |
|---|---|---|
| Australia | 108 | |
| Austria** | 92 | 87 |
| Belgium** | 92 | 92,5 |
| Bulgaria* | 92 | |
| Canada | 94 | |
| Croatia* | 95 | |
| Czech Republic* | 92 | |
| Denmark** | 92 | 79 |
| Estonia* | 92 | |
| European Community** | 92 | |
| Finland** | 92 | 100 |
| France** | 92 | 100 |
| Germany** | 92 | 79 |
| Greece** | 92 | 125 |
| Hungary* | 94 | |
| Iceland | 110 | |
| Ireland** | 92 | 113 |
| Italy** | 92 | 93,5 |
| Japan | 94 | |
| Latvia* | 92 | |
| Liechtenstein | 92 | |
| Lithuania* | 92 | |
| Luxembourg** | 92 | 72 |
| Monaco | 92 | |
| Netherlands** | 92 | 94 |
| New Zealand | 100 | |
| Norway | 101 | |
| Poland* | 94 | |
| Portugal** | 92 | 127 |
| Romania* | 92 | |
| Russian Federation* | 100 | |
| Slovakia* | 92 | |
| Slovenia* | 92 | |
| Spain** | 92 | 115 |
| Sweden** | 92 | 104 |
| Switzerland | 92 | |
| Ukraine* | 100 | |
| United Kingdom of Great Britain and Northern Ireland** | 92 | 87,5 |
| United States of America*** | 93 | |

* Countries that are undergoing the process of transition to a market economy (EITs).

**The EU's 15 member States will redistribute their targets among themselves, taking advantage of a scheme under the Protocol known as a "bubble". The EU has already reached agreement on how its targets will be redistributed.

*** The US has indicated its intention not to ratify the Kyoto Protocol.